MEASUREMENT OF THE $t\bar{t}$ PRODUCTION CROSS SECTION IN $p\bar{p}$ COLLISIONS AT $\sqrt{s} = 1.96$ TeV USING LEPTON + JETS EVENTS IN THE CDF DETECTOR AT FERMILAB

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Outline

- Introduction/Motivation

- Jet Probability Tagging Algorithm

  ◇ Description of the algorithm

  ◇ Efficiency

  ◇ Mistag rate

- $t\bar{t}$ Cross Section Measurement

  ◇ Data sample and event selection

  ◇ Acceptance and background estimate

  ◇ Discussion of the results

- Summary

The Tevatron

- Highest energy $p\bar{p}$ collider

  ◇ Energy of the beam = $980\ GeV$

  ◇ $\sqrt{s} = 1.96\ TeV$ (Run I $\rightarrow 1.8\ TeV$)

- Collisions every $396\ ns$ (Run I $3.5\ \mu s$)

- Currently, the world's only top quark production machine

- Run I: 1992 - 1996

  ◇ Quark top discovery

- Run II: 2001 - nowadays

  ◇ Top Mass, B$_s$ mixing, single top evidence

The CDF Detector

- General purpose particle detector. Cylindrical simmetry

- 3 subsystems: tracking (inside a $1.4\ T$ solenoidal magnetic field), calorimetry and muons systems

- For top physics, the full detector is needed
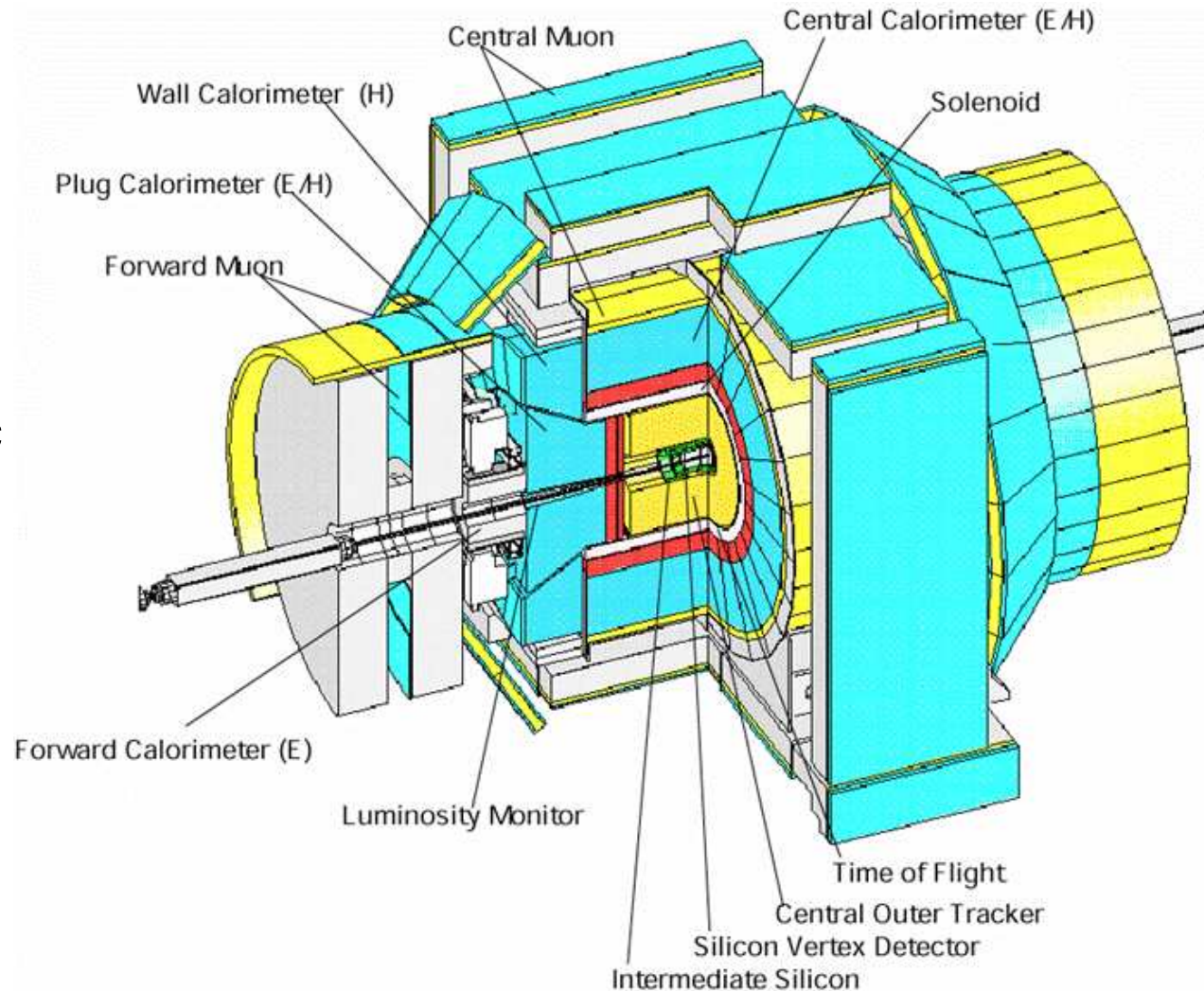
Why is the Top Quark so Interesting?

- **Heaviest** known fundamental particle $\Rightarrow$ probe physics at much higher energy scale

- **Decays before it can hadronize** ($\tau_{top} \sim 10^{-25}$ sec) $\Rightarrow$ momentum and spin pass to the decay products

- Top quark properties **test SM**

- Look for new physics

  ◇ Higher x-sec than predicted could be a sign of non SM production mechanisms

- Top mass **fundamental parameter** in SM

  ◇ M_t, along with the mass of the W, is related with the mass of the SM Higgs boson
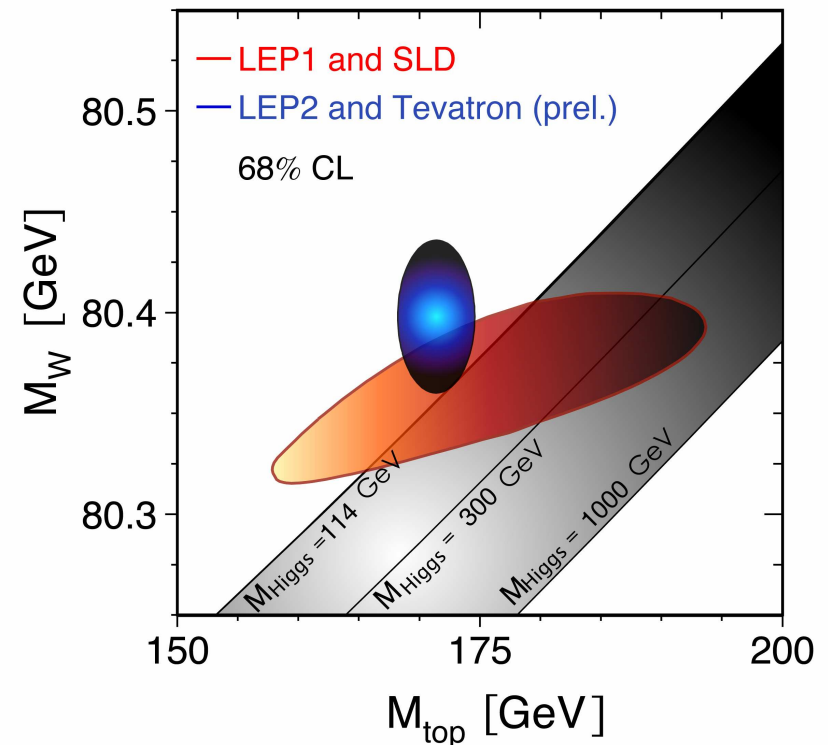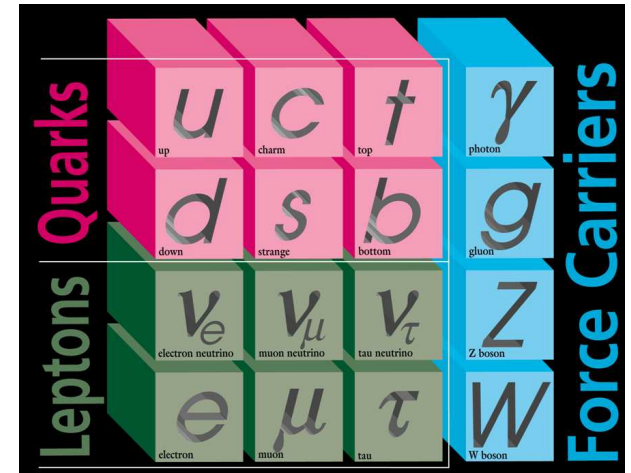
Top Production & Decay Modes

- At Tevatron energies ($\sqrt{s} = 1.96\ TeV$) top quark is mainly produced in pairs via strong interaction

  ◇ $q\bar{q}$ annihilation (85%) or gluon fusion (15%)
  ◇ $\sigma(p\bar{p} \to t\bar{t}\ @\ M_t = 178\ GeV) \approx 6.1\ pb \Rightarrow$ one top event every 10 billion inelastic collisions

- Decays via electroweak interaction $t \to Wb$

  ◇ BR($t \to Wb$)≈1 $\Rightarrow$ final state given by $W^{\pm}$ decays
  ◇ BR($W \to$ leptons) = 1/3, BR($W \to$ quarks) = 2/3

  lepton ≡ electron or muon

Final State	Dataset	BR	S/B
$l\nu\ l\nu\ bb$	dilepton	~5%	4/1
$l\nu\ qq\ bb$	lepton+jets	~30%	2/1
$qq\ qq\ bb$	hadronic	~44%	1/4
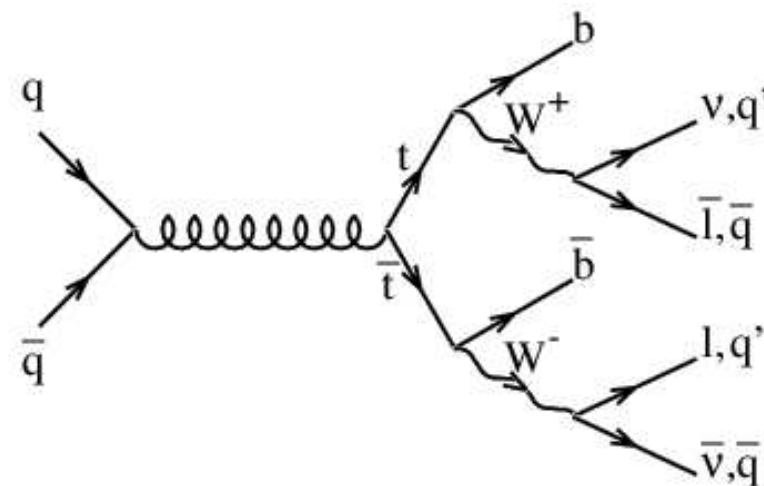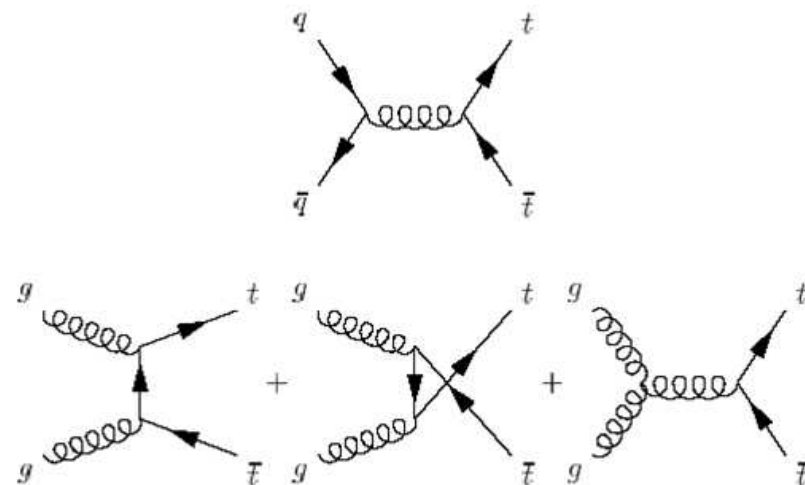
Detecting the Top Quark

- **Top events:**
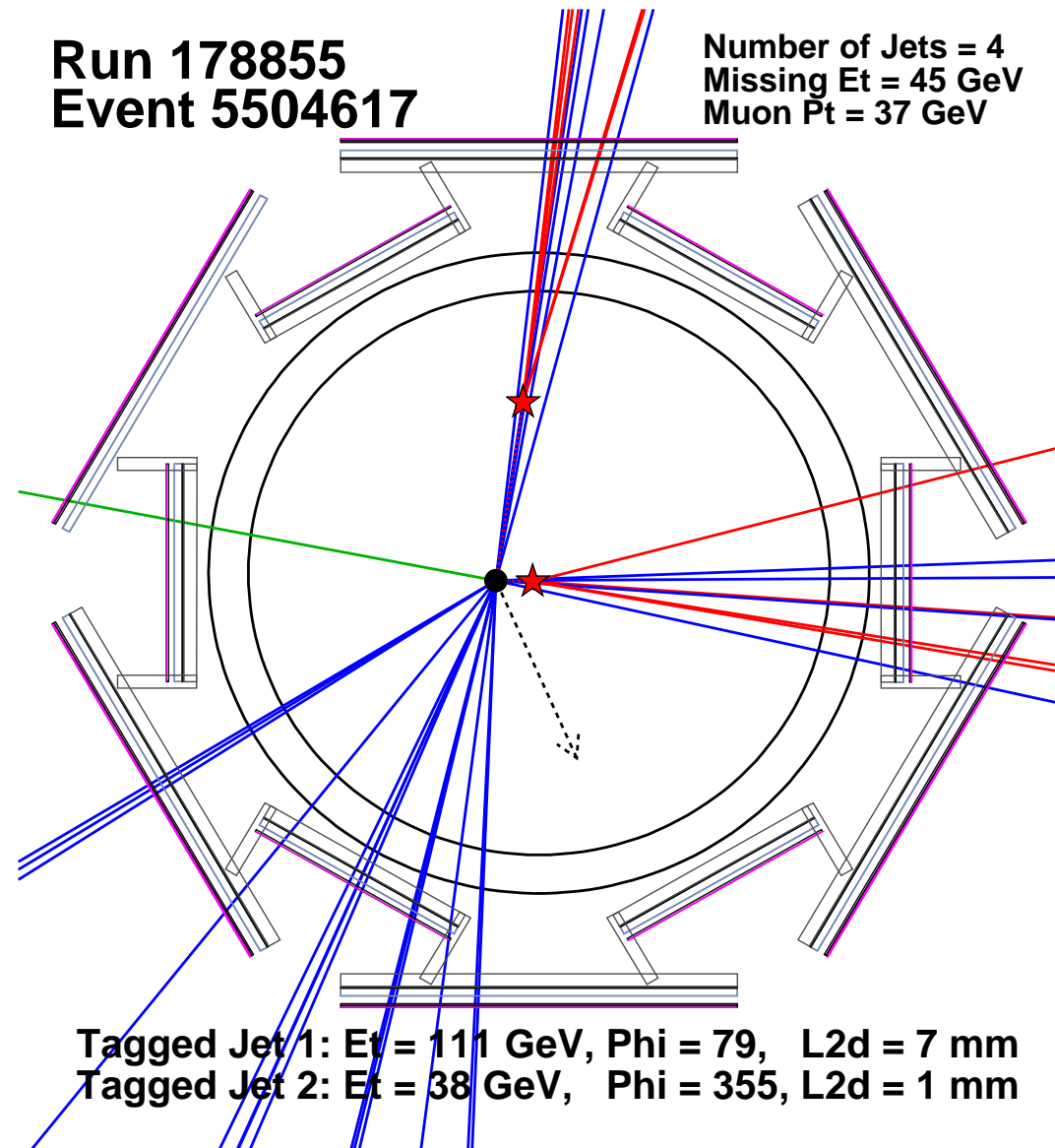
  ◇ are energetic, central and spherical
  ◇ have E_T from neutrinos in leptonic modes
  ◇ have jets with high E_T
  ◇ have two high E_T b-jets

- **Main backgrounds:**

  ◇ Dilepton: $Z \rightarrow l^- l^+$
  ◇ L+jets: $W + jets$ (few % have b or c)

- **Identifying b-jets improves S/B**

  ◇ Secondary Vertex Tagger
  ◇ Jet Probability Tagger
  ◇ Soft Lepton Tagger

Run 178855
Event 5504617

Number of Jets = 4
Missing Et = 45 GeV
Muon Pt = 37 GeV

Tagged Jet 1: Et = 111 GeV, Phi = 79, L2d = 7 mm
Tagged Jet 2: Et = 38 GeV, Phi = 355, L2d = 1 mm

B-Tagging at CDF

- B decay signature has a displaced vertex (long lifetime) travels $\Rightarrow L_{XY} \sim 3$ mm before decaying

- **Secondary Vertex** Tagger

  ◇ Fit displaced tracks to a common vertex and cut on L_{XY} significance

  ◇ Relies heavily on excellent performance and understanding of the silicon tracker

- **Jet Probability** Tagger

  ◇ Joint probability for all tracks in a jet to come from a primary vertex

- **Soft Lepton** Tagger: looks for an energetic lepton inside a jet

  ◇ B can decay semileptonically: $b \rightarrow l\nu c$
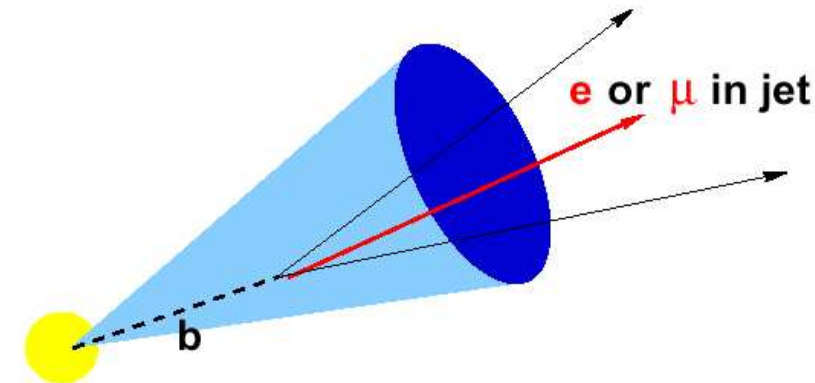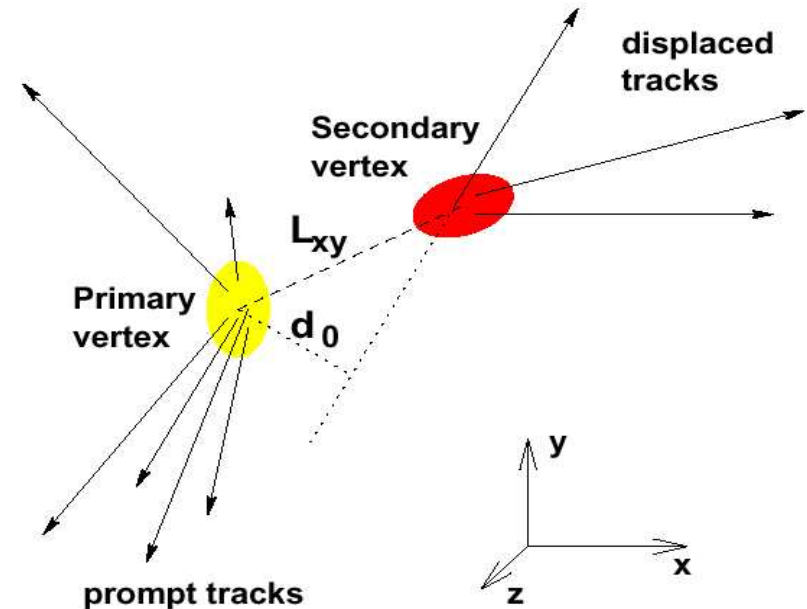
- $b \rightarrow \ell\nu c$ (BR $\sim 20\%$)
- $b \rightarrow c \rightarrow \ell\nu s$ (BR $\sim 20\%$)

Jet Probability

- ... heavy flavor (HF) tagging?

  ◇ Top signal has 2 b's

  ◇ ~5% of the main backgrounds has HF

  ⇒ S/B greatly increased
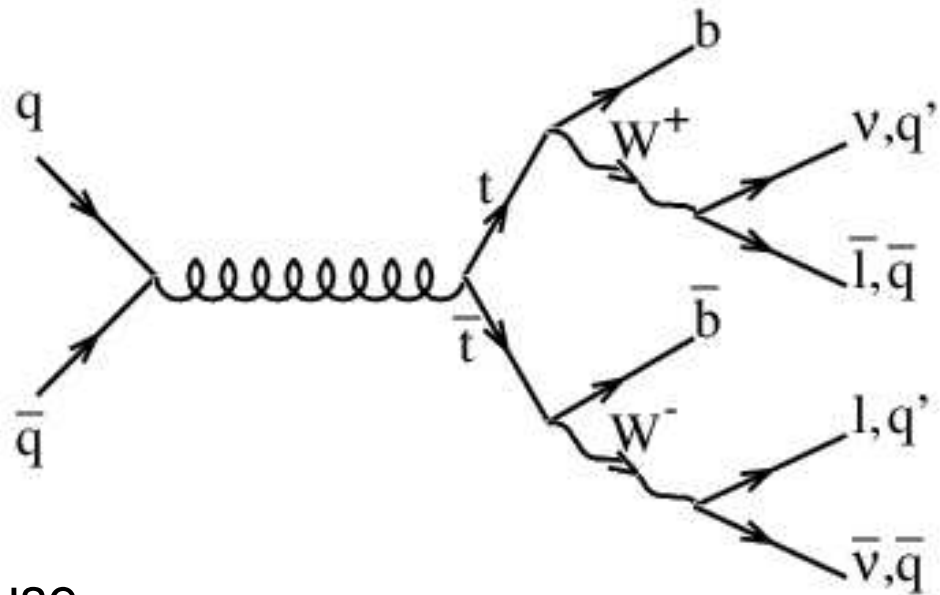
- Jet Probability is characterized because...

  ◇ Provides a continuous variable ⇒ more flexible way to understand the composition of the tagged sample

  ◇ Can be tuned/optimized differently for other kind of analyses

  ◇ This method can be used to separate b and c heavy flavor contributions

Jet Probability Algorithm (I)

- Signed impact parameter: $d_0 > 0$ if point of closest approach to the primary vertex lies in the same direction as the jet direction ($\cos \phi > 0$)
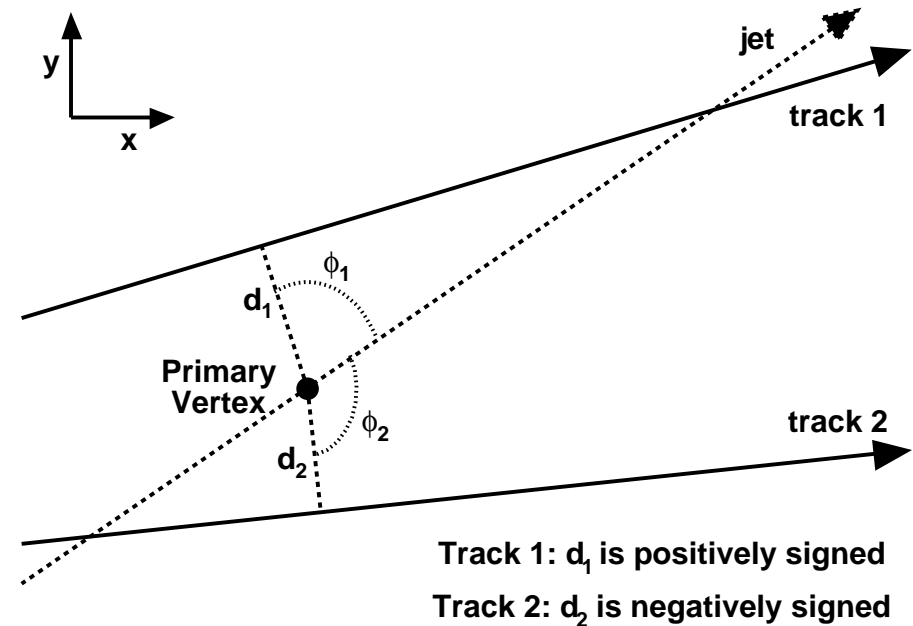
- **+** (−) Jet Probability: only tracks with positive (negative) impact parameter

  - ◇ + Jet Probability ⇒ positive tags

  - ◇ − Jet Probability ⇒ mistags prediction

- Track impact parameter significance: $S_{d_0} = d_0/\sigma_{d_0}$

Track 1: d_1 is positively signed

Track 2: d_2 is negatively signed
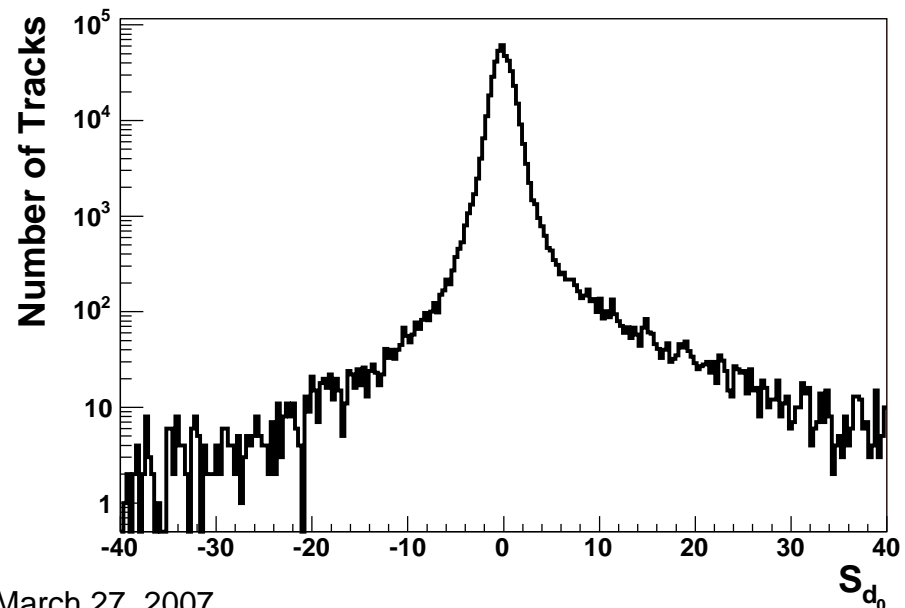
Jet Probability Algorithm (II)

- Fit the negative side of the track impact parameter significance distribution (only detector resolution effects) to obtain a resolution function $R(S)$ (different for data and MC)

- $R(S)$ used to determine the probability $(P_{tr}(S_{d_0}))$ that the impact parameter significance of a given track is due to the detector resolution

$$P_{tr}(S_{d_0}) = \frac{\int_{-\infty}^{-|S_{d_0}|} R(S)dS}{\int_{-\infty}^{0} R(S)dS}$$

- Probability that a jet is consistent with a zero lifetime hypothesis:

$$P_J = \prod_{l=1}^{N_{tr}} P_{tr} \times \sum_{k=0}^{N_{tr}-1} \frac{(-ln \prod_{l=1}^{N_{tr}} P_{tr})^k}{k!}$$
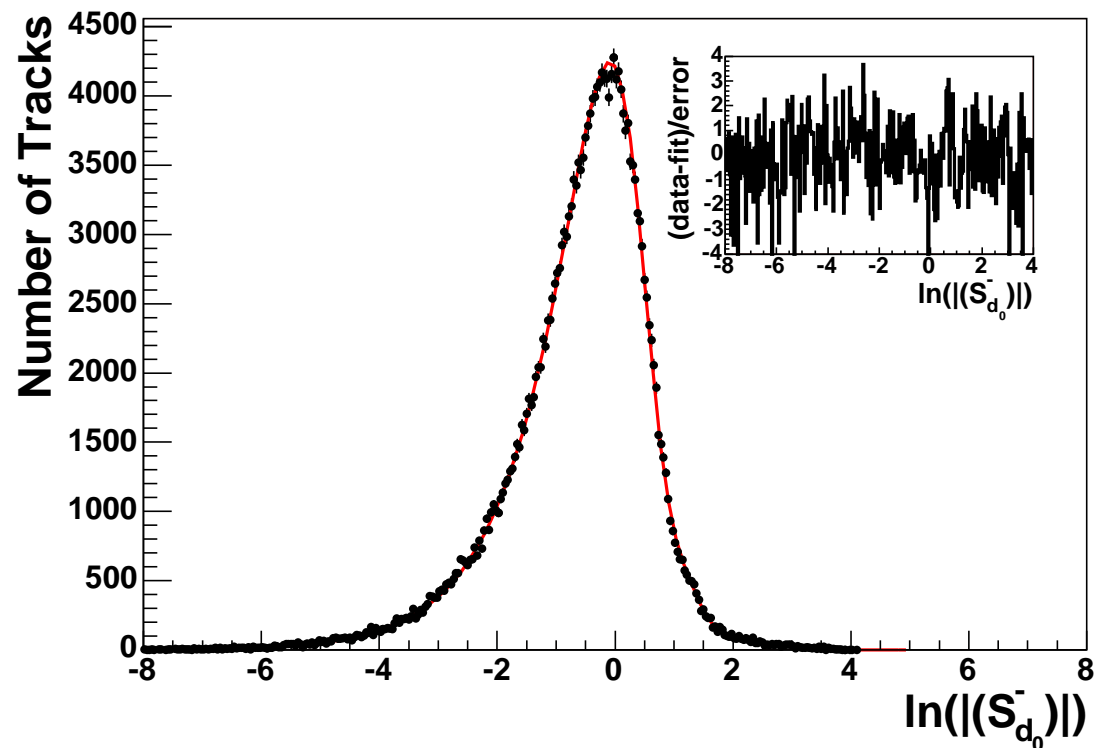
Deduction of the Jet Probability Formula

- If we have a jet with 2 tracks with positive impact parameter which probabilities are P_1 and P_2 and $K \equiv P_1 \cdot P_2$

$$0 \leq P_i \leq 1 \text{ i=1,2} \implies 0 \leq K \leq 1$$

- The area below and in the left of the curve of constant probability K is the set of combinations, for the 2 tracks, of having a probability less or equal than K. And this area is defined as Jet Probability, P_J

$\diamond \ P_J = A + B, \ A = K \cdot 1$

$\diamond \ B = \int_{x=K}^{x=1} f(x)dx = \int_{x=K}^{x=1} \frac{K}{x}dx = -KLnK$

$\implies P_J = K(1 - LnK)$

- In general, it can be shown that

$$P_J = \prod_{l=1}^{N_{tr}} P_{tr} \times \sum_{r=0}^{N_{tr}-1} \frac{(-ln \prod_{l=1}^{N_{tr}} P_{tr})^r}{r!}$$

$K = P_1 P_2$
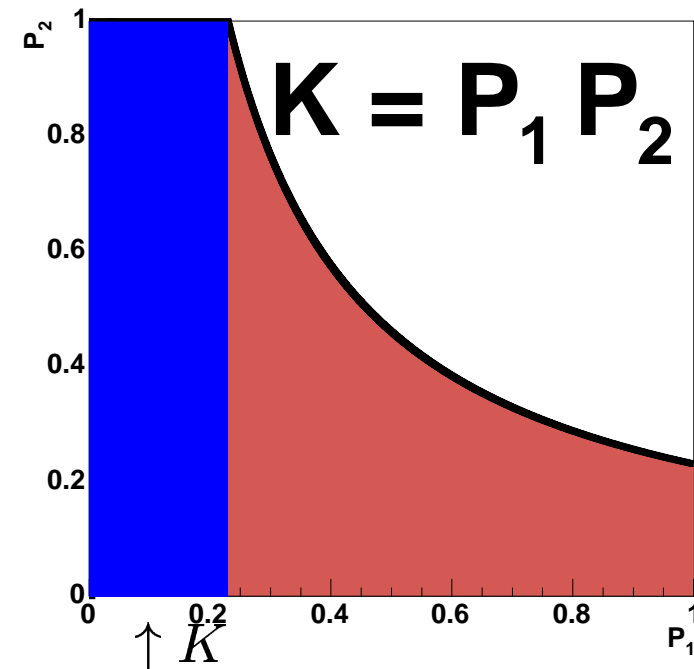
Jet Probability Algorithm (III)

- HF hadrons have long lifetime $\implies$ displaced vertices (and tracks) from the primary vertex

- Physically, probability for a jet to come from the primary vertex

- Uniform for light quark or gluon jets. Peaks at 0 for jets containing displaced tracks from HF decays

- For the analysis, $P_J < 1\%$ and $P_J < 5\%$
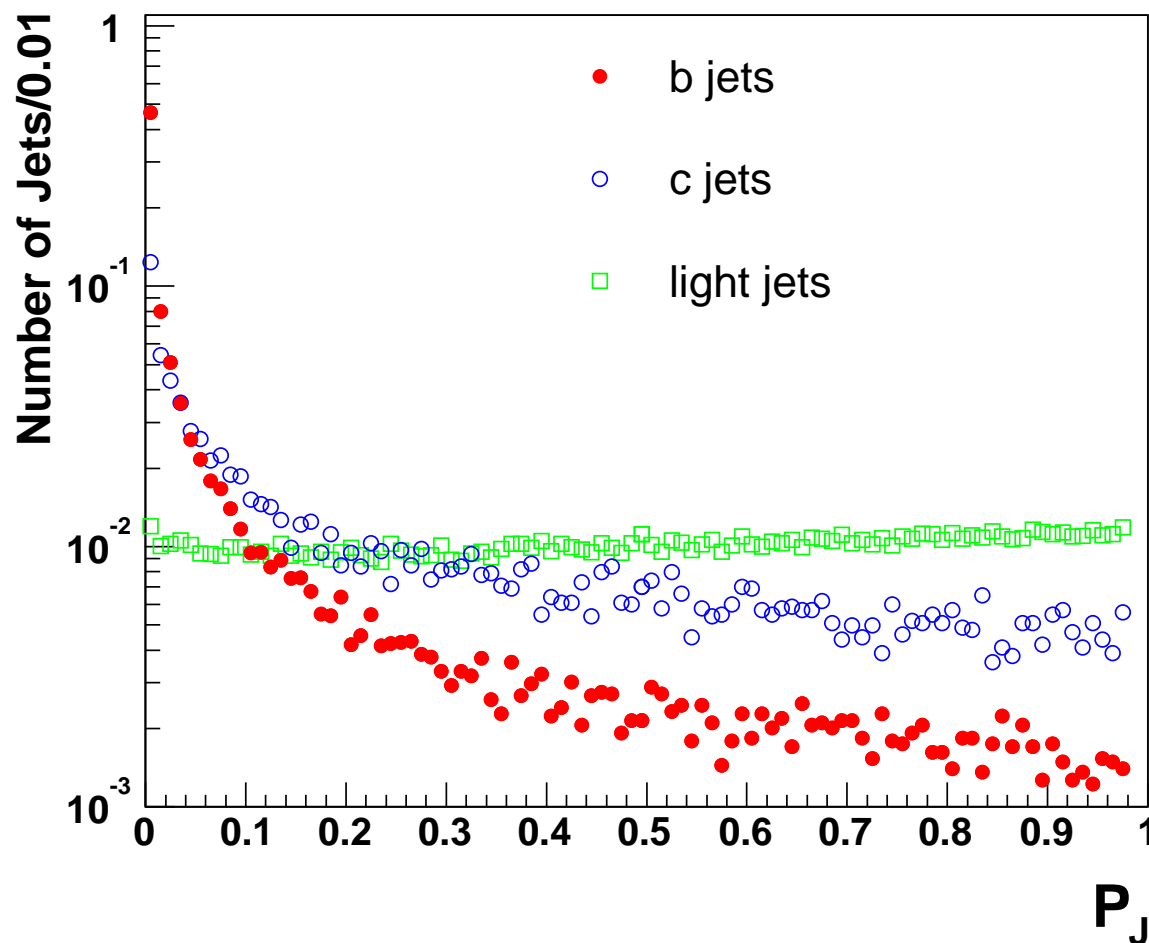
Jet Probability Efficiency (I)

- Measured using an 8 GeV inclusive electron data sample (it is enriched with HF due to the semileptonic B decays)

- Single tag method: $\epsilon = \frac{N_{ej}^{+}}{N_{ej}} \rightarrow \epsilon = \frac{N_{ej}^{+} - N_{ej}^{-}}{N_{ej}} \rightarrow \epsilon = \frac{N_{ej}^{+} - N_{ej}^{-}}{N_{ej}} \cdot \frac{1}{F_{HF}}$

  ◇ Disadvantage: relays on the correct determination of the heavy flavor fraction in the sample

- Double tag method: as heavy flavor quarks are mostly produced in pairs, heavy flavor content in one jet is enhanced requiring that the "other" jet (away jet) is tagged
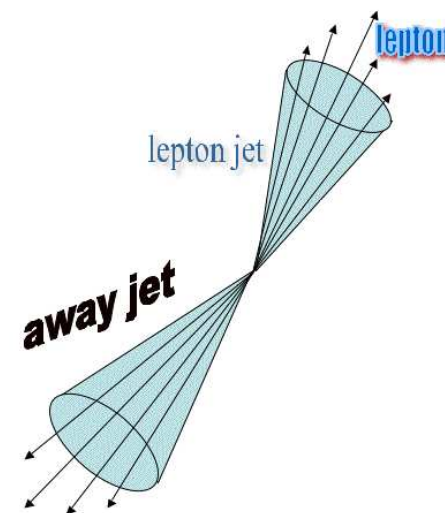
Jet Probability Efficiency (II)

- If there were no light jets mistagged as b-jets: $\epsilon = \dfrac{N_{a+}^{e+}}{N_{a+}} \cdot \dfrac{1}{F_{HF}^{a}}$

- But this is not true so:

$$\epsilon = \frac{(N_{a+}^{e+} - N_{a+}^{e-}) - (N_{a-}^{e+} - N_{a-}^{e-})}{N_{a+} - N_{a-}} \cdot \frac{1}{F_{HF}^{a}}$$

◇ F_{HF}^{a} is the fraction of HF e-jets for which the away jet is tagged

$$F_{HF}^{a} = 1 - P(1 - F_{HF})$$

◇ P is the probability to positively tag the away jet in an event where the e-jet is a light jet

◇ F_{HF} is the total HF fraction of e-jets

$$F_{HF} = F_b + F_c = F_b \times (1 + F_{c/b})$$

◇ F_b (F_c) is the total b (c) fraction of e-jets

Jet Probability Efficiency (III)

- There are 2 methods to calculate F_b

  ◇ Reconstruct $D^0 \to K\pi$ decays and use the invariant mass sidebands to substract backgorunds: $F_b = \frac{N_{D0}}{N_{ej}} \cdot \frac{1}{\epsilon_{D0}}$

  ◇ From cascade muons: select b-hadrons with 2 semileptonic decays (b $\to$ c $\to$ X) emitting a pair e-μ with opposite charge: $F_b = \frac{1}{\epsilon_\mu} \frac{N_{ej}^\mu(OS) - N_{ej}^\mu(SS)}{N_{ej}}$

F_b	$F_{c/b}$	F_{HF}	F_{HF}^a
0.16 ± 0.02	0.61 ± 0.10	0.26 ± 0.06	0.71 ± 0.05

- Efficiencies to tag a heavy flavor jet with $E_T > 15$ GeV and 318 pb^{-1}

	$P_J < 1\%$	$P_J < 5\%$
ϵ^{data}	0.258 ± 0.018	0.334 ± 0.026
ϵ^{MC}	0.316 ± 0.021	0.392 ± 0.026

Efficiency vs E_T^{jet} ($P_J < 1\%$) in inclusive electron sample
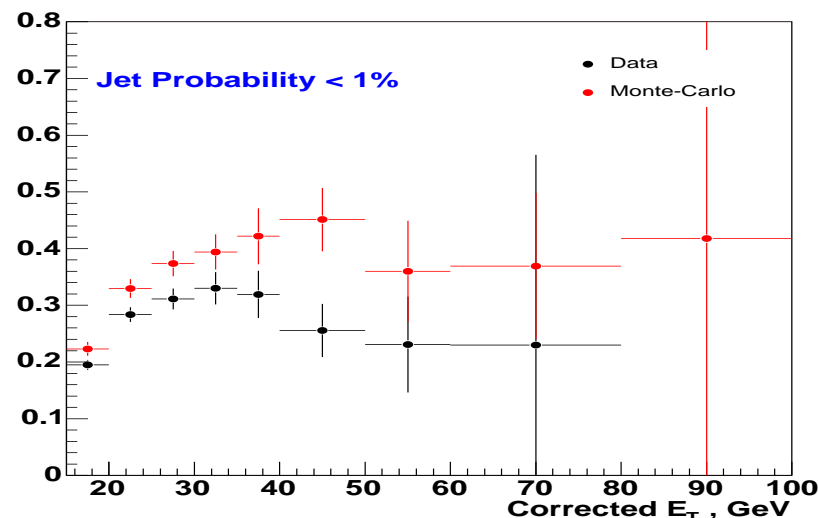
Jet Probability Efficiency in $t\bar{t}$ Events

- b-tagging efficiency (tag rate $\times$ SF) per jet in a top Monte Carlo sample. Bands represent the systematic error due to the scale factor.

JetProb Tag Efficiency for Top b-Jets

Jet Probability < 5%

Jet Probability < 1%

Top MC scaled to match data

Only b-jets with pseudorapidity<1

b-tag efficiency — jet E_T (GeV)

JetProb Tag Efficiency for Top b-Jets

Jet Probability < 5%

Jet Probability < 1%

Top MC scaled to match data

Only b-jets with Et>15 GeV

b-tag efficiency — jet pseudorapidity
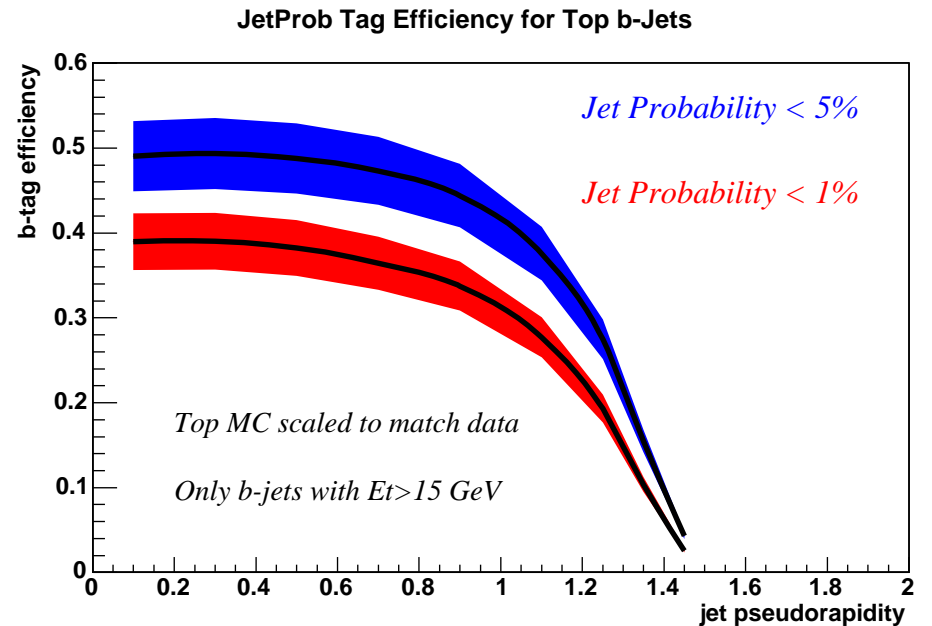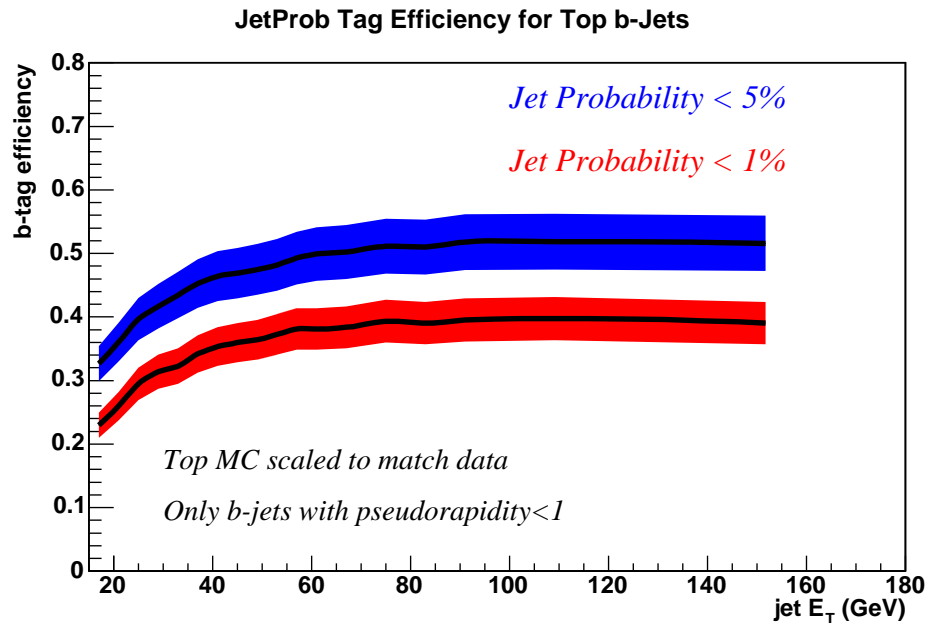
b-tagging efficiency (%)	$P_J < 1\%$	$P_J < 5\%$
per b-jet	35 ± 3	47 ± 4
per $t\bar{t}$ event	55 ± 4	69 ± 4

Scale Factor

- Scale Factor is the ratio between the data and Monte Carlo efficiencies

	$P_J < 1\%$	$P_J < 5\%$
Scale Factor (SF)	0.817 ± 0.070	0.852 ± 0.072

- Studied the SF dependence with E_T in two other samples and assume it is flat

- Large uncertainty: BR(B $\to l\nu D^0 X$), difference between data and MC in ϵ_{D^0} ($\sim 10\%$), assumption in symmetry between negative tags and positive mistags ($\sim 7\%$)

- We assume the same SF for c-jets but increase the uncertainty in 100%
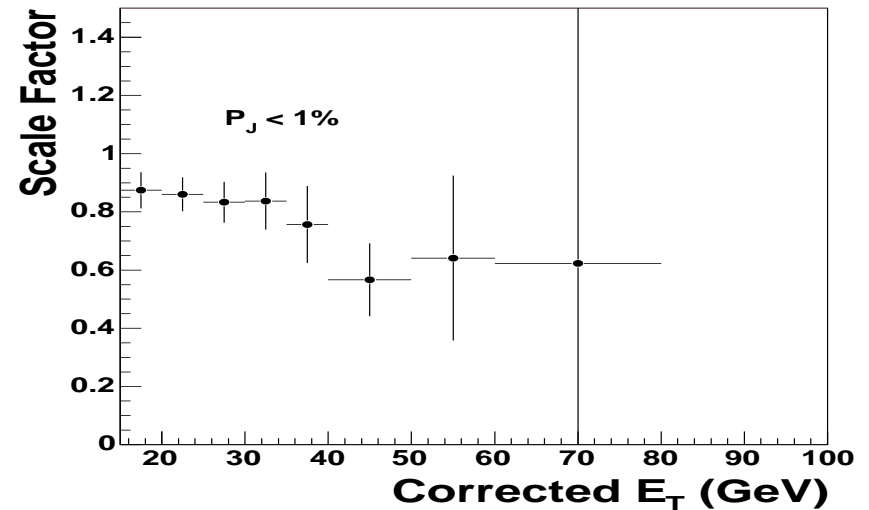
Jet Probability Mistag Rate

- Mistag rate: probability of tagging a light jet as a heavy flavor one

- Determined using 4 inclusive jet data samples (jet20, 50, 70 and 100)

- Parameterized as a 6 dimensional look-up table (mistag matrix): E_T, N_{trk}, $\sum E_T^j$, η, Z_{vtx}, ϕ

  ◇ E_T, N_{trk} and $\sum E_T^j$ to describe physics and kinematics of the jets

  ◇ η, Z_{vtx} and ϕ to take into account detector geometry

- Positive (negative) rate = $\dfrac{\#\ jets\ positively\ (negatively)\ tagged}{\#\ taggable\ jets}$

- Results with 318 pb^{-1}

	$P_J < 1\%$	$P_J < 5\%$
Overall negative tag rate (%)	1.22 ± 0.08	5.30 ± 0.25

Jet Probability Mistag Rate: Checks

- **Consistency**: compare tag rates observed in the odd numbered events to the tag rates predicted by a matrix built only using the even numbered events

- **Predictivity**: same as above but for the tag rates as a function of variables not included in the matrix (number of vertices, run number, instantaneous luminosity)

- **Sample dependence**: compare the observed tag rates from the multijet trigger to the tag rates predicted by the tag rate matrix (inclusive jet data)
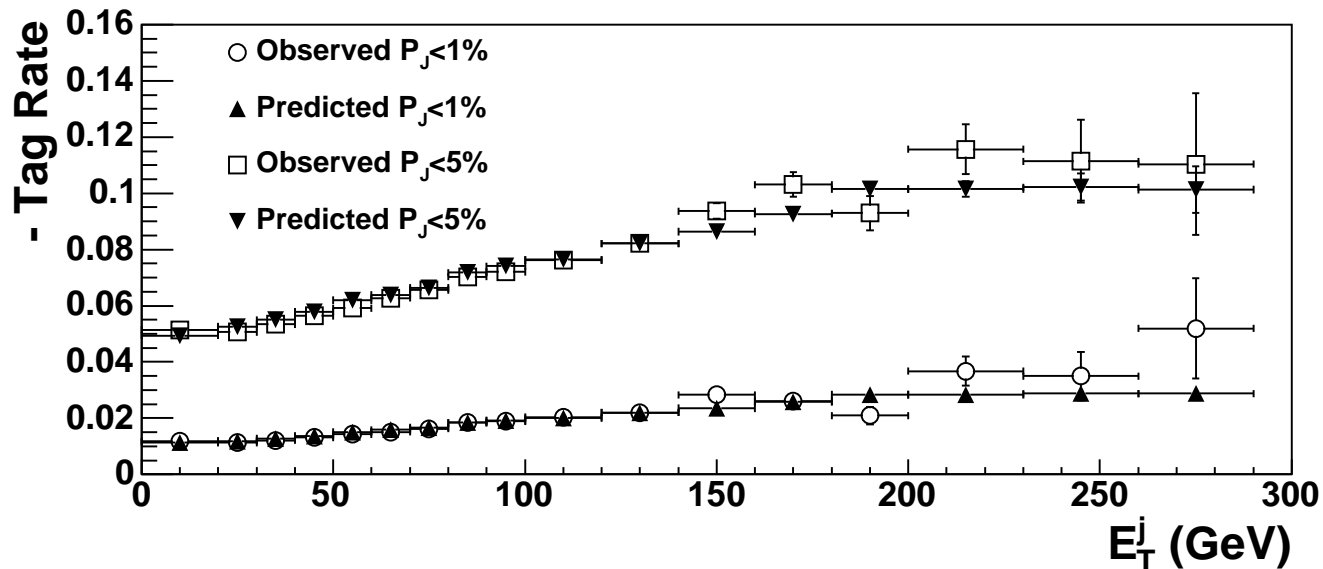
Jet Probability Mistag Rate: Systematics

- Compare the observed and predicted tag rates in different data samples

- Apply matrices built using different inclusive jet subsamples to different datasets

Matrix	Sample	Obs./Pred. Pos. Tag Rate Ratio	Obs./Pred. Neg. Tag Rate Ratio
Inc. Jet Even	Inc. Jet Odd	0.997 ± 0.002	0.999 ± 0.003
Inc. Jet Even	Jet20 Odd	0.987 ± 0.003	0.970 ± 0.006
Inc. Jet Even	Jet50 Odd	0.991 ± 0.003	0.998 ± 0.006
Inc. Jet Even	Jet70 Odd	0.997 ± 0.004	0.996 ± 0.006
Inc. Jet Even	Jet100 Odd	0.989 ± 0.003	1.029 ± 0.005
Jet20 All	Jet50 All	1.020 ± 0.003	1.044 ± 0.008
Inc. Jet Even	Trig. Jet Odd	0.976 ± 0.002	0.978 ± 0.004
Inc. Jet Even	Non trig. Jet Odd	1.028 ± 0.003	1.028 ± 0.005
Inc. Jet All	$\sum E_T^{jet}$ All	1.037 ± 0.002	0.966 ± 0.003

- Largest deviation is taken as systematic uncertainty due to the sample dependence of the matrix

Jet Probability Mistag Rate vs E_T and η
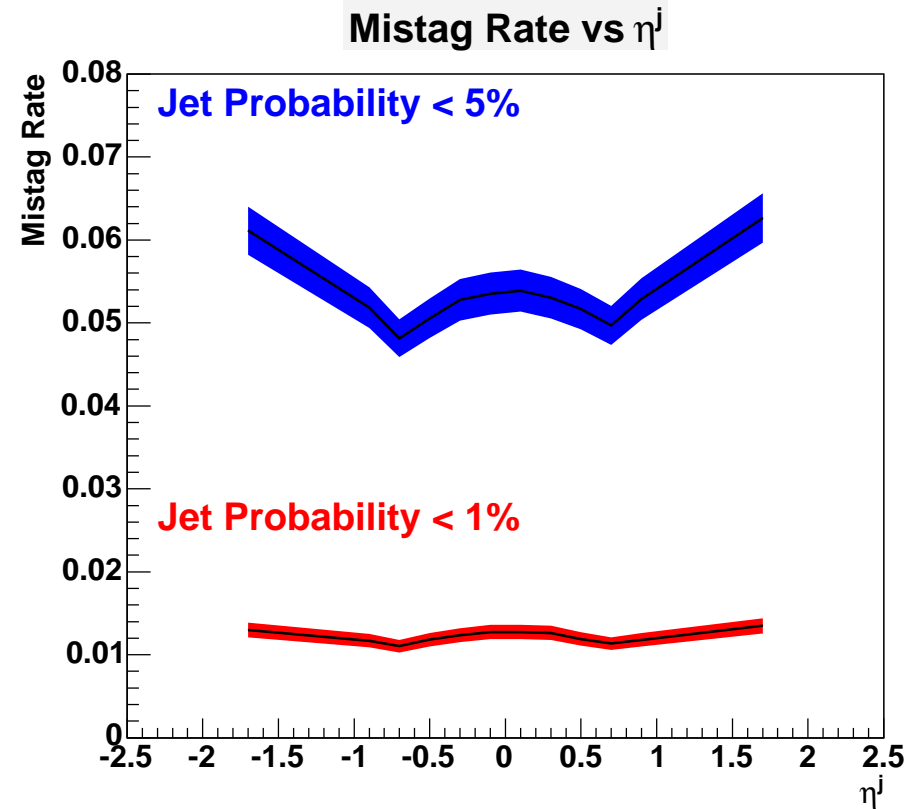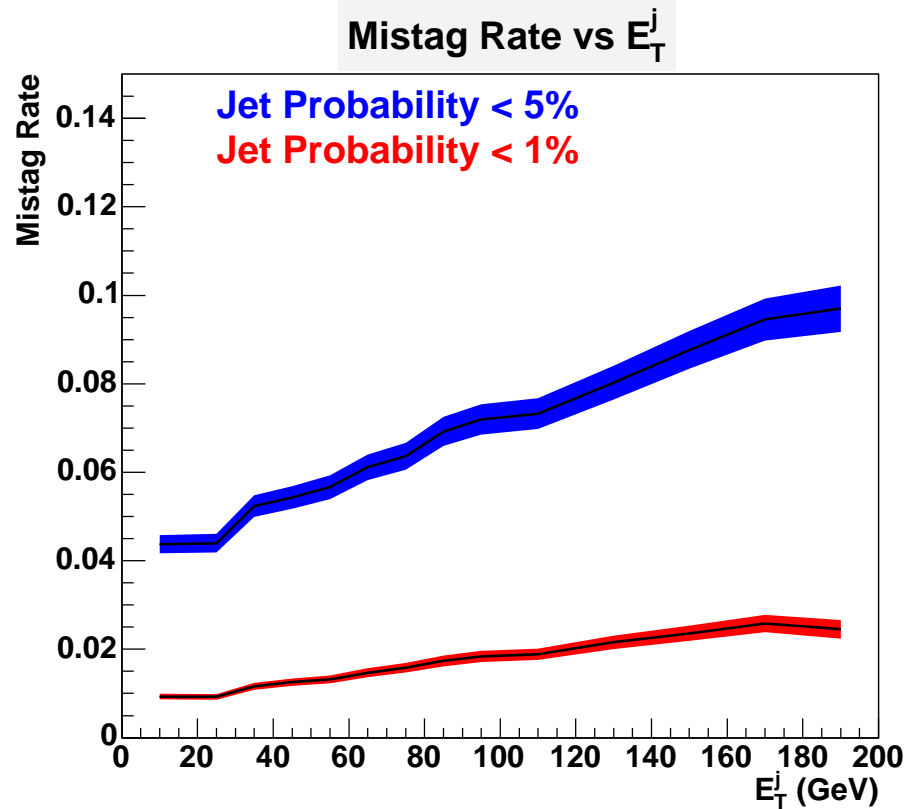
- Bands represent the total uncertainty (statistical and systematic added in quadrature).

Jet Probability Mistag Rate: Asymmetry (I)

- Rate of negative tag jets does not completely describe the rate of positive mistags of light jets due to residual lifetime effects from Λ's and K's or interactions with the detector $\Rightarrow$ need to know the flavor composition of the tagged jets in data

- Fit a variable (sensitive to the flavor content of the jet: $max(d_0)$, $max(S_{d_0})...$) in data to MC templates for b, c and light jets

- Fit only positive excess (subtracting negative tags from the positive side)

- Normalize the number of negative tags from b, c and light jets in MC to the number of negative tags in data

- Extract the fractions of b, c and light jets in data from the fit
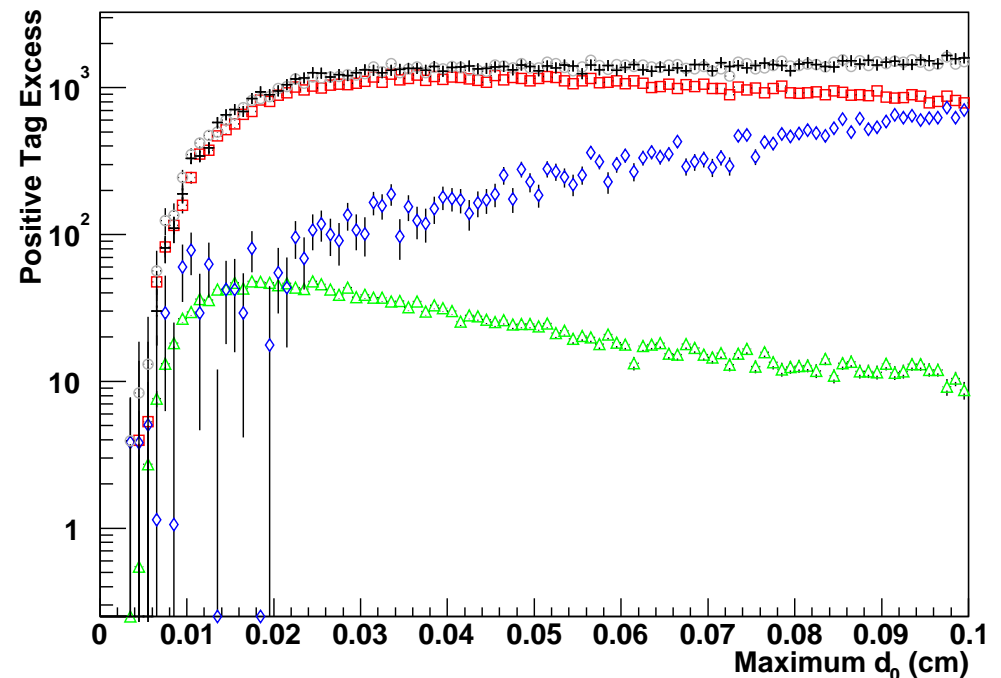
Jet Probability Mistag Rate: Asymmetry (II)

- Results of the fit for the six variables used

Fitted variable	β ($P_J < 1\%$)	β ($P_J < 5\%$)
Maximum d_0	1.64 ± 0.02	1.37 ± 0.02
Maximum S_{d_0}	1.56 ± 0.03	1.10 ± 0.02
Mass of the system of tracks with $|d_0| > 0.01\ cm$	1.51 ± 0.04	1.30 ± 0.02
Mass of the system of tracks with $S_{d_0} > 2$	1.43 ± 0.03	1.20 ± 0.02
$P_T^{rel.}$ of the system of tracks with $|d_0| > 0.01\ cm$	1.67 ± 0.03	1.32 ± 0.02
$P_T^{rel.}$ of the system of tracks with $S_{d_0} > 2$	1.57 ± 0.02	1.30 ± 0.02
Average	1.56 ± 0.14	1.27 ± 0.17

- For the analysis, will scale up the mistag prediction by the asymmetry factor β

Comparison with other b-Tagging Algorithms

- Efficiencies and mistag rates for the b tagging algorithms used at CDF

	$P_J < 1\%$	$P_J < 5\%$	Tight SecVtx	Loose SecVtx	SLT
Efficiency (%)	~55	~69	~60	~69	~15
Mistag rate (%)	~1.2	~5.3	~0.5	~1.2	~4

- Three different taggers that use different information

  ◇ Overlap Jet Probability - SecVtx ~80%.

- Allow measure the same property using different taggers in order to reduce systematic effects

Physics analysis

TOP PHYSICS IS HUGE!!!
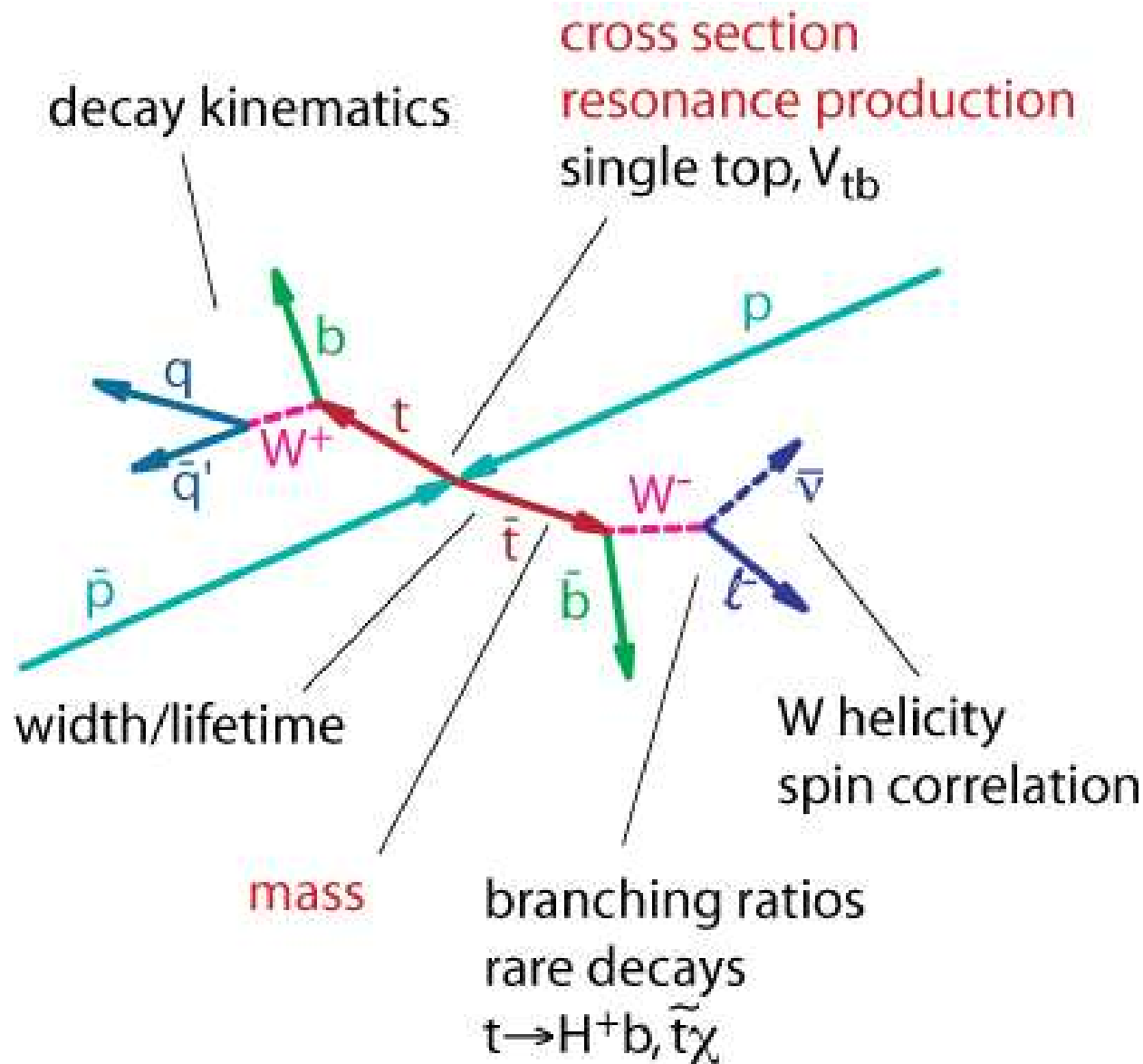
$t\bar{t}$ Cross Section Measurement

- Counting experiment:

$$\sigma_{t\bar{t}} = \frac{N_{obs} - N_{bkg}}{\epsilon_{t\bar{t}} \times \int L\,dt}$$

- Goal: demonstrate good understanding of the backgrounds in the control region and of the top contribution in the signal region
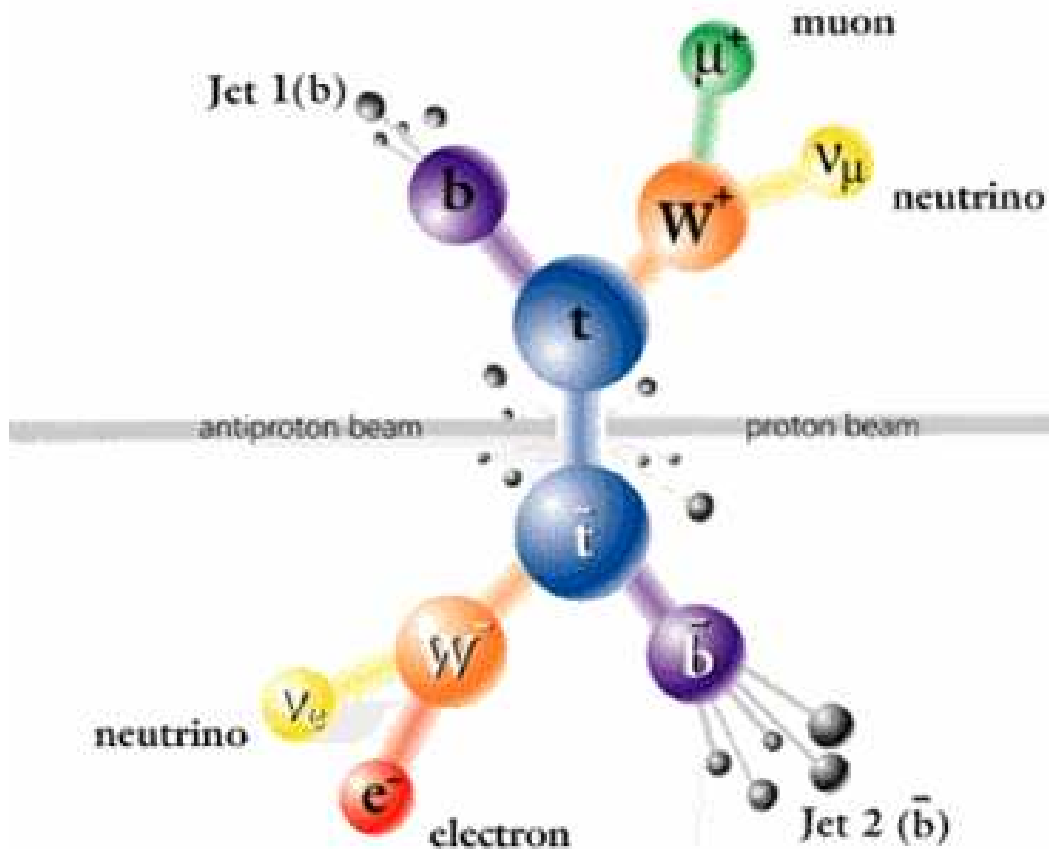
Data Sample

- Data sample based on Run II data taken untill September 2004

- Triggers based on the selection of a lepton with high p_T

	CEM (Central electrons, $|\eta| < 1$)	CMUP (Central muons, $|\eta| < 0.6$)	CMX (Extension muons, $0.6 < |\eta| < 1$)
Lum (pb^{-1})	318.5 ± 18.8	318.5 ± 18.8	305.2 ± 18.0

- Electron identification: isolated track with $p_T > 9$ GeV that extrapolates to 3 CEM adjacent towers with $E_T > 20$ GeV

- Muon identification: isolated COT track with $p_T > 20$ GeV that extrapolates to a track segment in the muon chambers

- Jets are reconstructed from calorimeter towers using a cone algorithm with radius $R \leq 0.4$

Event Selection

- 1 high p_T isolated lepton

- High missing transverse energy

- ≥ 3 energetic jets

- Vetoes (dilepton, cosmics, conversion, z_{vtx})

- $M_T^W > 20$ GeV and $H_T > 200$ GeV

Jet Multiplicity	1 jet	2 jets	3 jets	≥ 4 jets
Before b-tagging				
# Events	29339	4442	300	166
After b-tagging ($P_J < 1\%$)				
# Events	350	191	52	68
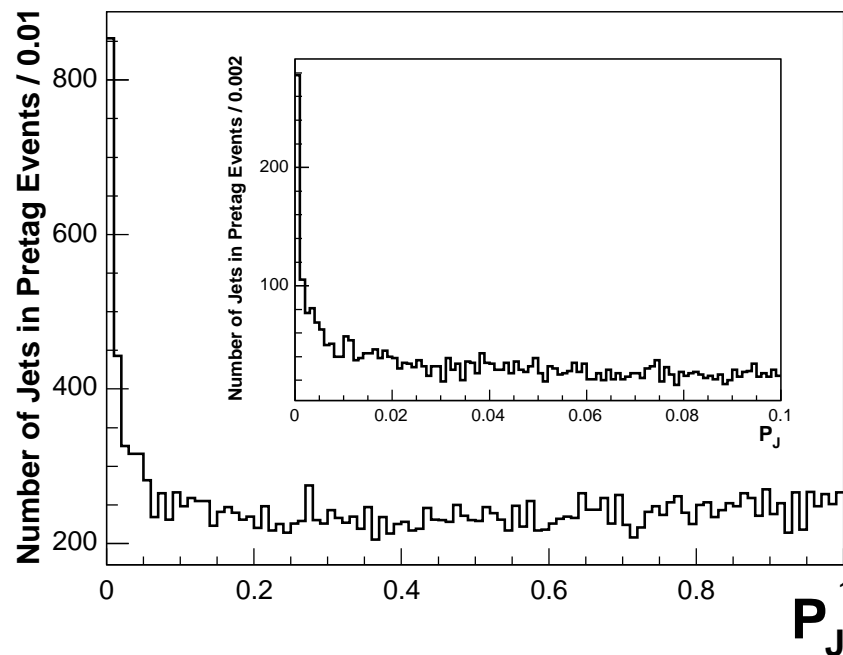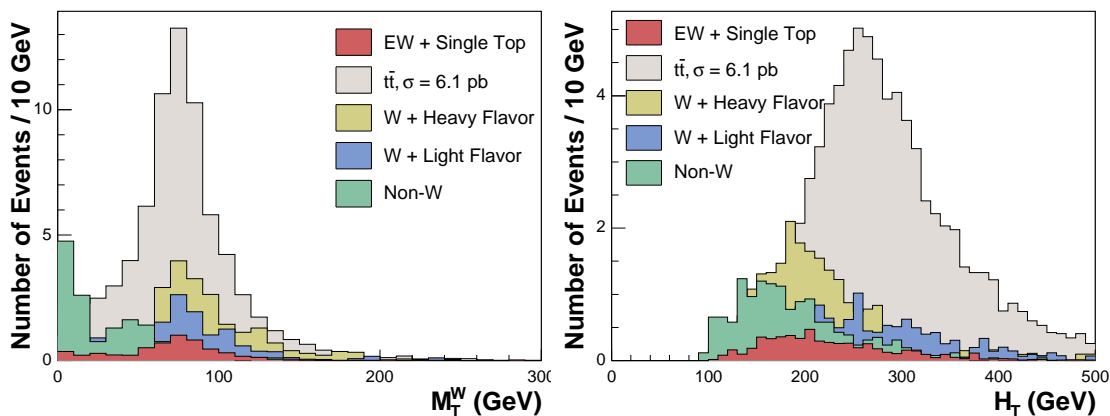
- ≥ 1 tagged jet (jet with positive $P_J < 1\%$)

A Top Candidate Event looks like this...

- Jets are represented by yellow hashed cones

- For tagged jets, positive impact parameter tracks are drawn red

- All other (good r-phi) tracks inside jet are drawn blue

- Missing transverse energy direction is the dotted arrow

- Electron track is magenta

Run 166614
Event 804529

Number of Jets = 4
Missing Et = 28 GeV
Electron Et = 113 GeV

Tagged Jet 1: Et = 51 GeV,   Phi = 238, JP = 1.56e-04
Tagged Jet 2: Et = 26 GeV,   Phi = 72,   JP = 4.10e-03
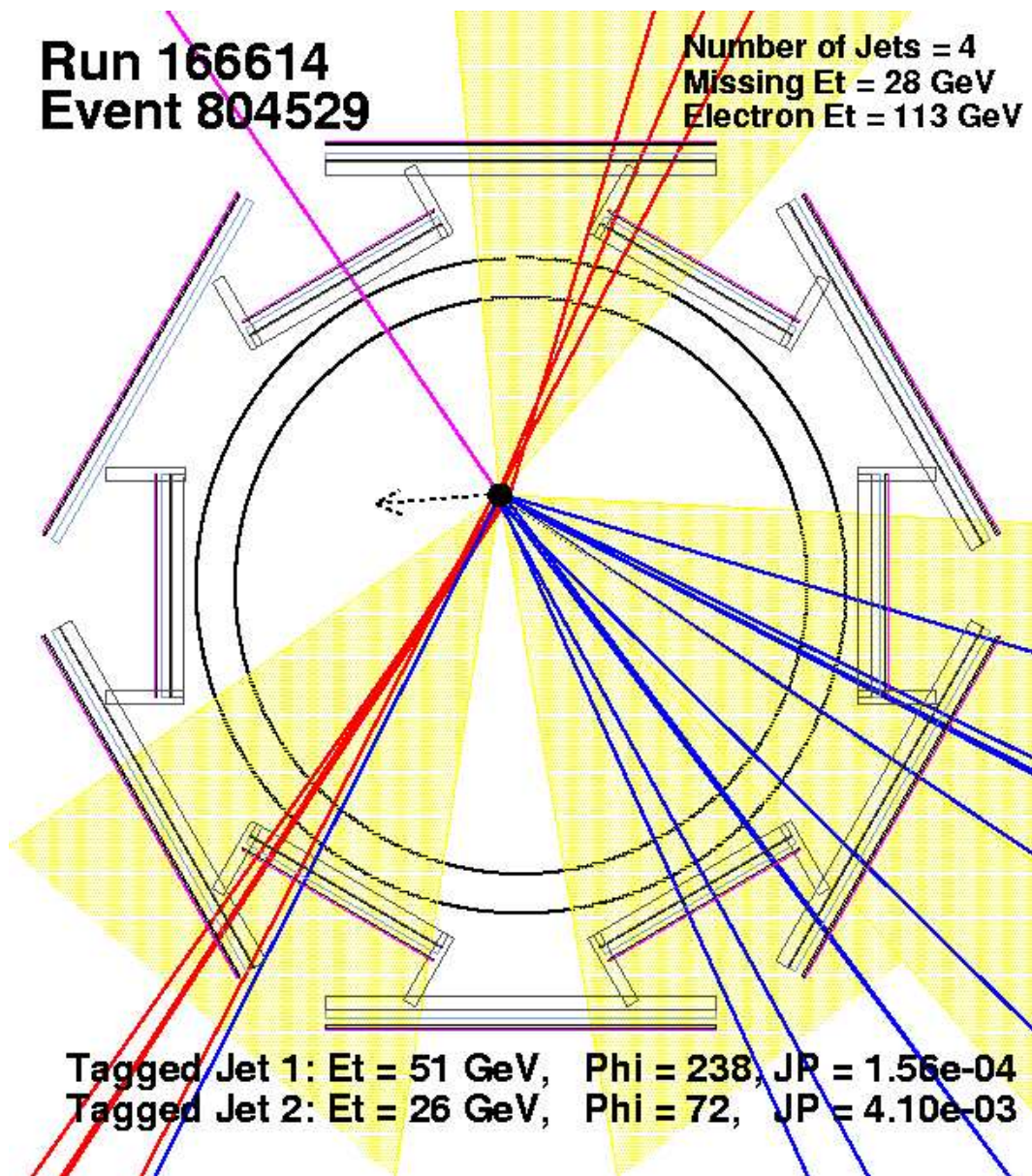
Acceptance (I)

$$\epsilon_{t\bar{t}} = (A_{t\bar{t}} \times K_{lep} \times \epsilon_{trig} \times \epsilon_{z_0}) \times \epsilon_{b-tag} = \epsilon_{t\bar{t}}^{\text{pretag}} \times \epsilon_{b-tag}$$

- $A_{t\bar{t}}$: fraction of MC t$\bar{\text{t}}$ events passing the kinematic requirements (including the lepton+jets branching ratio and lepton identification efficiencies)

- K_{lep}: scale factor that takes into account the difference in lepton identification efficiency between data and MC using Z$\to l^+ l^-$ events (0.996, 0.874 and 0.989)

- ϵ_{trig}: trigger efficiency for identifying high p$_T$ leptons. Measured using data, $W^{\pm} \to e^{\pm} \nu$ and $Z \to \mu^+ \mu^-$ (0.962, 0.908 and 0.965)

- ϵ_{z_0}: efficiency of the z vertex cuts (vertex is required to be within 60 cm of the center of the detector, 0.951 from minimum bias data, and 5 cm with respect to the vertex with highest $\sum p_T$, 0.98)

- ϵ_{b-tag}: efficiency to tag at least one tight jet in a t$\bar{\text{t}}$ event (includes the scale factor)

Acceptance (II)

- t$\bar{\text{t}}$ events from a `PYTHIA` Monte Carlo sample with M_t = 178 GeV/c^2

Quantity	CEM	CMUP	CMX
Single tag, JP<1% (SF = 0.82 $\pm$ 0.07)			
Acc. No Tag	3.67 $\pm$ 0.02 $\pm$ 0.22	1.92 $\pm$ 0.01 $\pm$ 0.12	0.751 $\pm$ 0.008 $\pm$ 0.046
Tag Eff.	54.7 $\pm$ 0.2 $\pm$ 3.6	54.1 $\pm$ 0.3 $\pm$ 3.5	55.2 $\pm$ 0.5 $\pm$ 3.6
Average Tag Eff.	54.5 $\pm$ 0.2 $\pm$ 3.6		
Acc. with Tag	2.00 $\pm$ 0.01 $\pm$ 0.18	1.04 $\pm$ 0.01 $\pm$ 0.09	0.41 $\pm$ 0.01 $\pm$ 0.04
$\epsilon_{t\bar{t}} \int$L dt (pb^{-1})	6.38 $\pm$ 0.04 $\pm$ 0.68	3.30 $\pm$ 0.03 $\pm$ 0.36	1.32 $\pm$ 0.02 $\pm$ 0.14

Backgrounds

- W + heavy flavor jets

- W + light jets (mistags)

- Non-W

- Electroweak processes

Backgrounds: W + Heavy Flavor Jets

- Events with a real W in association with quarks or gluons

- Estimated using W + heavy flavor MC

  ◇ Extract the HF fractions and the b-tag efficiencies from $\frac{W+HF}{W+Jets}$ MC

  ◇ Normalized to W+jets pretag data

  ◇ Contribution to the pretag sample: $N_{HF}^{pretag} = F_{HF} \times N_{obs}^{pretag}$

  ◇ Contribution to the tagged sample: $N_{HF}^{tag} = N_{HF}^{pretag} \times \epsilon_{btag}$

- 12.3% of the lepton + jets tagged sample
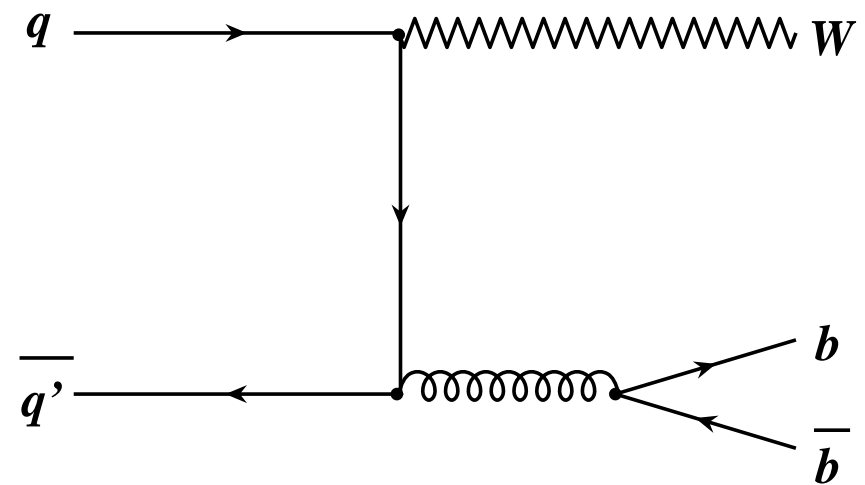
Backgrounds: Mistags

- Jets from light partons or gluons that are tagged

- Negative tags in data have large uncertainty

- Predicted, from data, by the negative tag rate matrix

  ◇ Count events in the pretag sample

  ◇ Weight by the probability of having one mistagged jet

  ◇ Correct by the mistag asymmetry factor

- Accounts for 12.8% of the observed number of events

Backgrounds: non-W

- Events for which the lepton+$\not{E}_T$ signature is not due to the decay of a W

- QCD jet production where a jet fakes a lepton and the $\not{E}_T$ is due to a bad measurement of the jet energies

- Minimized with the cut in $M_T^W > 20$ GeV

- Instrumental background not modelled by MC so derived from a control region in data

  ◇ Assumes that the lepton isolation and the $\not{E}_T$ of the event are uncorrelated for QCD processess $\Rightarrow \frac{N_B}{N_A} = \frac{N_D}{N_C}$

  ◇ Not optimum method. Make 3 different estimations and assign a 50% uncertainty

- 1.2% of the tagged sample
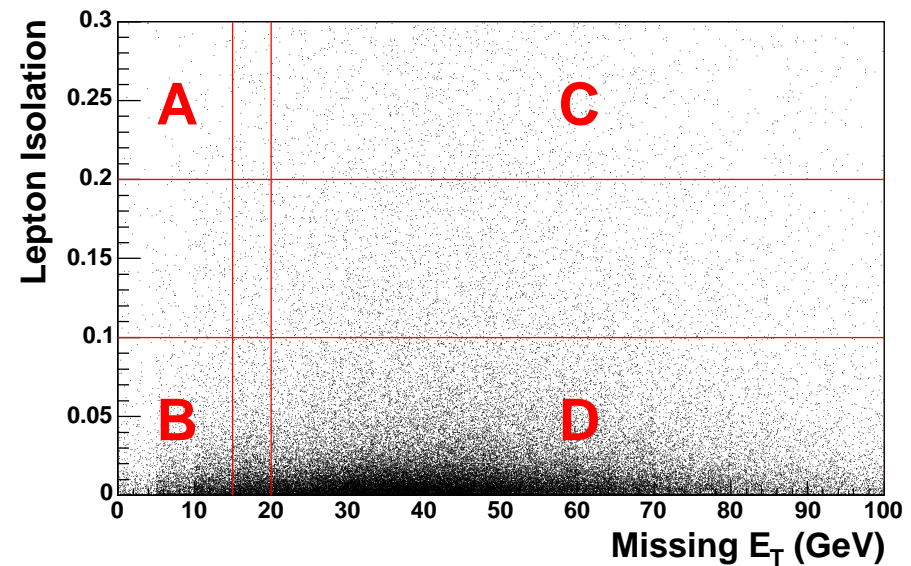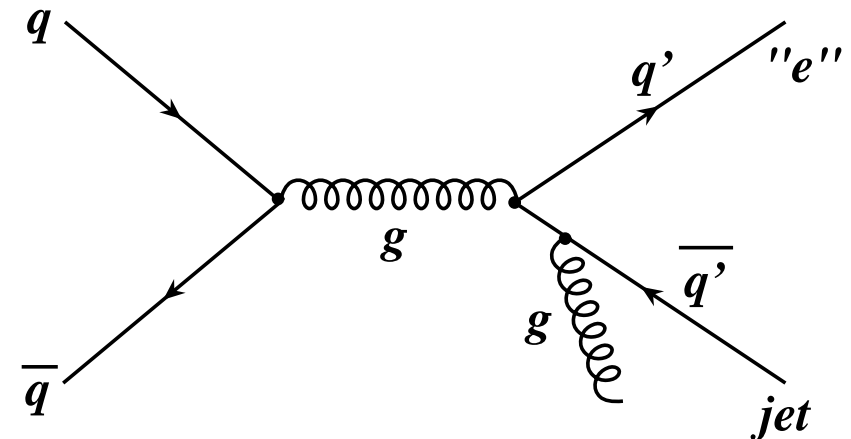
Backgrounds: Electroweak Processes

- Dibosons: One boson decays leptonically and the other hadronically producing a b tag

- $Z \to \tau\tau$: one τ fakes the W signature and the other one is tagged

- Single top: W (from the top) decays leptonically

- Predicted from MC using the theoretical cross sections (2.5%)
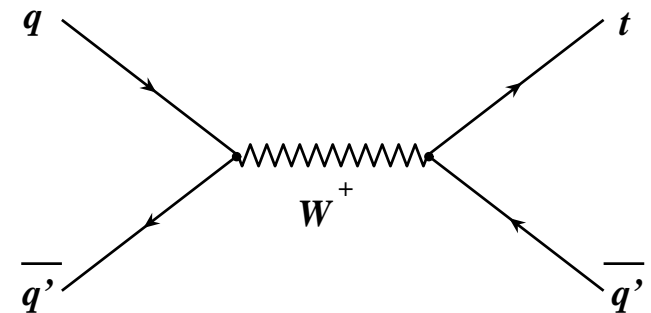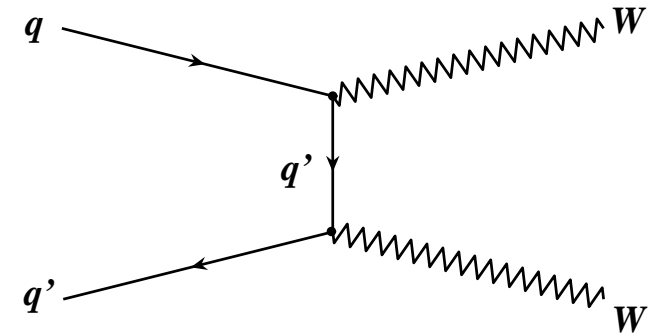
Process	Cross Section (pb)
WW	13.25 ± 0.25
WZ	3.96 ± 0.06
ZZ	1.58 ± 0.02
Single Top $W - g$ (t-channel)	1.98 ± 0.08
Single Top W^* (s-channel)	0.88 ± 0.05
$Z \to \tau^+\tau^-$	254.3 ± 5.4

Background Summary, $P_J < 1\%$

Jet Multiplicity	1 jet	2 jets	3 jets	$\geq$ 4 jets
Pretag Data	29339	4442	300	166
Electroweak	9.3 ± 1.1	16.6 ± 1.8	2.3 ± 0.3	0.71 ± 0.09
$Wb\bar{b}$	83 ± 23	47 ± 13	4.3 ± 1.2	1.1 ± 0.3
$Wc\bar{c}$	31 ± 9	17.3 ± 5.2	1.6 ± 0.5	0.4 ± 0.1
Wc	86 ± 21	19.0 ± 4.9	1.0 ± 0.3	0.21 ± 0.06
Mistag	149 ± 17	51 ± 6	6.1 ± 0.7	2.2 ± 0.3
Non-W	31 ± 16	8.6 ± 4.6	0.9 ± 0.6	0.5 ± 0.5
Total Background	389 ± 49	159 ± 22	16.3 ± 2.0	5.1 ± 0.7
$t\bar{t}$ (8.9 pb)	2.5 ± 0.5	20.6 ± 2.4	40.4 ± 4.5	58.1 ± 6.2
Data	350	191	52	68

Results for $P_J < 1\%$
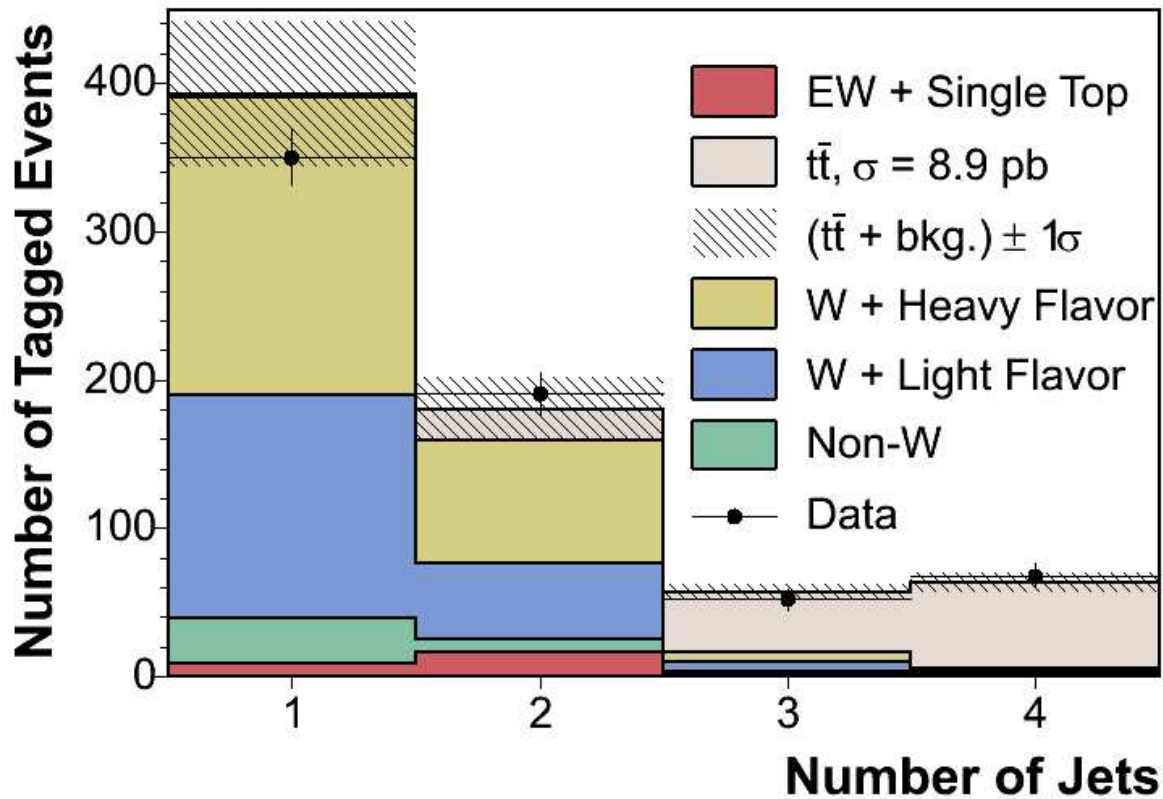
$\sigma_{t\bar{t}}$ (pb)	Single Tag
$P_J < 1\%$	8.9 ± 1.0 (stat) $^{+1.1}_{-1.0}$(syst)

Systematic Uncertainties ($P_J < 1\%$)

- Already systematically limited

- Largest uncertainties due to the tagging SF, jet energy scale and luminosity

- For future measurements, focus on reducing systematics

  ◇ Tagging SF

  ◇ Jet energy scale

Source	Fractional Uncert. (%)	Contribution to $\sigma_{t\bar{t}}$ (%)
Central Electron ID	1.6	+0.99/-0.97
Central Muon ID	1.9	+0.61/-0.61
CMX Muon ID	1.8	+0.22/-0.22
PDF	2	+2.1/-2.0
Jet Energy Scale	4.2	+4.5/-4.2
ISR/FSR	1.3	+1.4/-1.3
MC Modeling	1.6	+1.7/-1.6
Z Vertex	2.0	+2.1/-2.1
Tagging SF (b's/c's)	8.6/12.9	+8.2/-7.2
Non-W Prediction	50	0.71
W+HF Prediction	30	2.6
Cross Sections Bkg.	1.8	0.056
Luminosity	5.9	+6.5-5.7
Total		+12.5/-11.3

$\sigma_{t\bar{t}}$ dependence with M_t

- Reevaluate signal acceptance using `HERWIG` Monte Carlo samples with different values of M_t
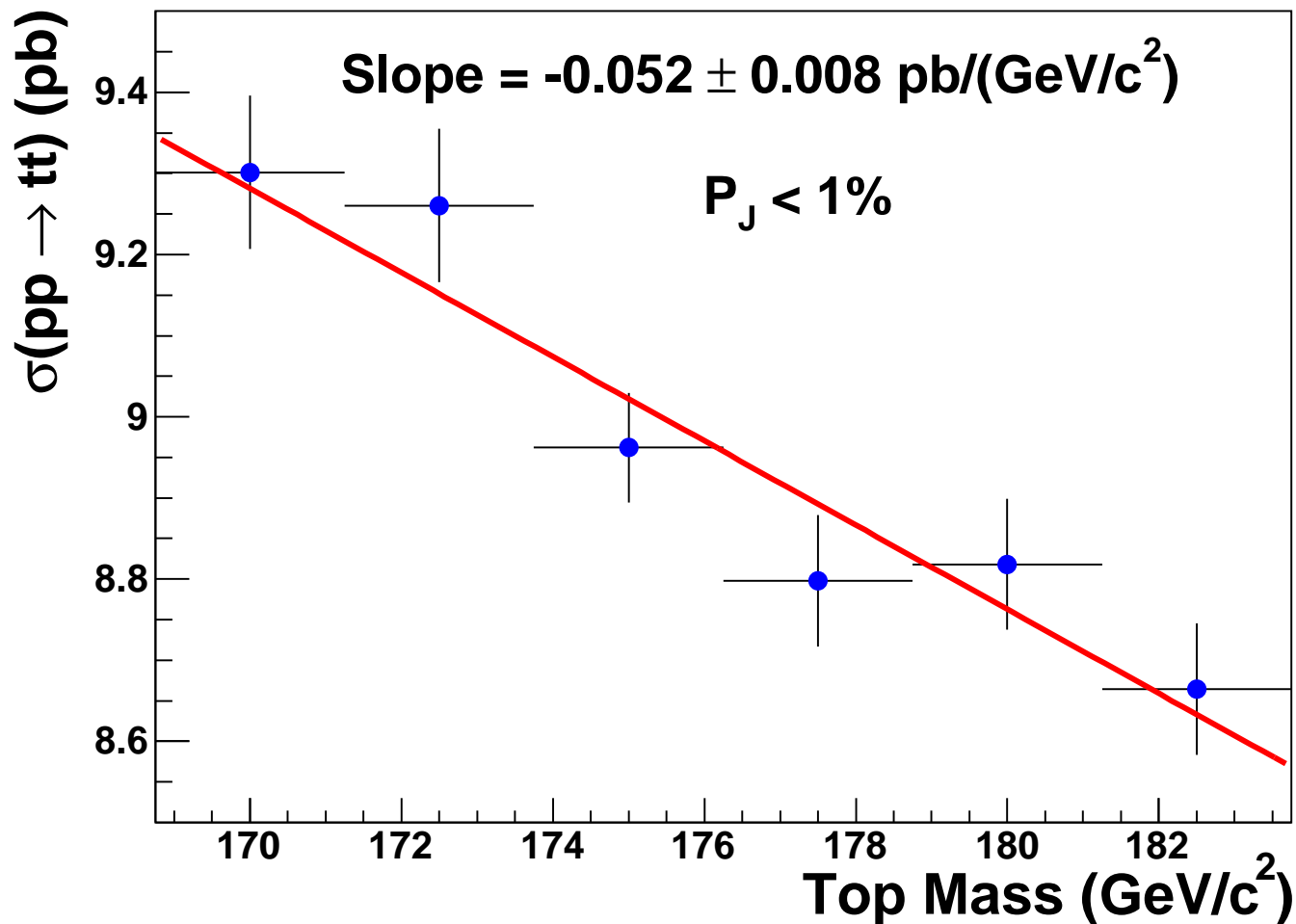
Cross Check (I): Double tag $P_J < 1\%$
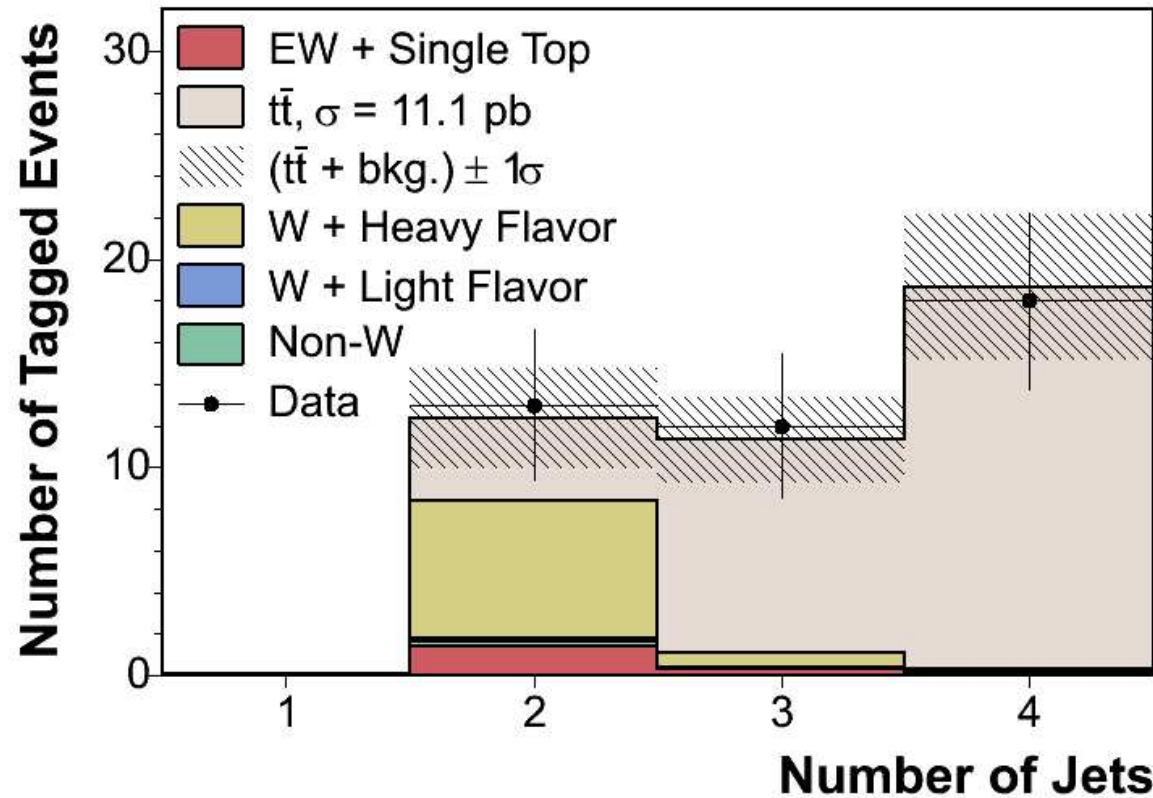
$\sigma_{t\bar{t}}$ (pb)	Single Tag	Double Tag
$P_J < 1\%$	8.9 ± 1.0 (stat) $^{+1.1}_{-1.0}$ (syst)	$11.1^{+2.3}_{-1.9}$ (stat) $^{+2.5}_{-1.9}$ (syst)

Cross Check (II): $P_J < 5\%$
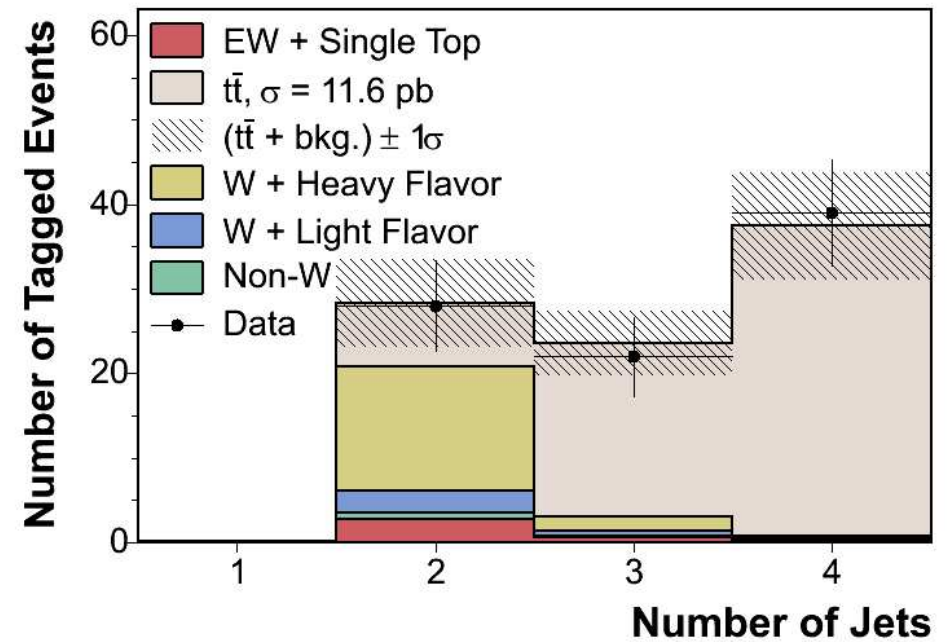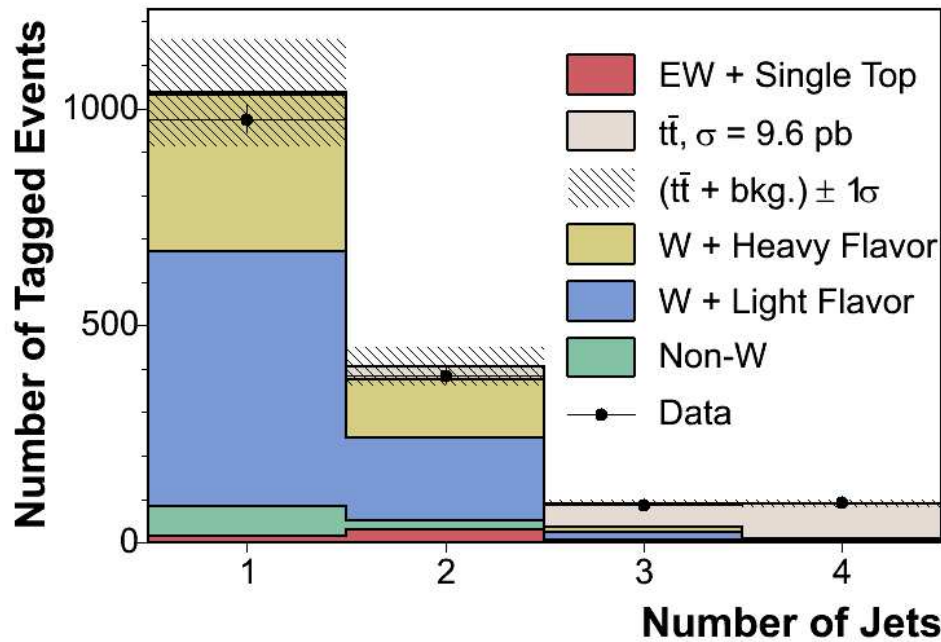
$\sigma_{t\bar{t}}$ (pb)	Single Tag	Double Tag
$P_J < 1\%$	8.9 ± 1.0 (stat) $^{+1.1}_{-1.0}$ (syst)	$11.1^{+2.3}_{-1.9}$ (stat) $^{+2.5}_{-1.9}$ (syst)
$P_J < 5\%$	$9.6^{+1.0}_{-0.9}$ (stat) $^{+1.2}_{-1.1}$ (syst)	$11.6^{+1.7}_{-1.5}$ (stat) $^{+2.4}_{-1.8}$ (syst)

Single vs Double Tag Cross Section

- Measurements are statistically compatible but $\sigma_{2t}/\sigma_{1t} \simeq 1.2...$

- We did 10,000 pseudoexperiments varying the total double tag background according to a Gaussian with a width equal to its uncertainty

- Add the background to the expected signal assuming σ_{1t} and vary the total number of events according to a Poisson distribution

- Count number of times the result is greater than σ_{2t}: Prob($\sigma_{meas} > \sigma_{2t} \mid \sigma_{1t}$)

	SF - $1\,\sigma$	SF	SF + $1\,\sigma$
$P_J < 1\%$	4.5%	13.2%	30%

P_J	# tags	SF - $1\,\sigma$	SF	SF + $1\,\sigma$
1%	≥ 1	$9.8^{+1.1}_{-1.0}$(stat.)$^{+1.3}_{-1.1}$(syst.)	$8.9^{+1.0}_{-1.0}$(stat.)$^{+1.1}_{-1.0}$(syst.)	$8.3^{+1.0}_{-0.9}$(stat.)$^{+1.0}_{-0.9}$(syst.)
1%	≥ 2	$13.3^{+2.8}_{-2.3}$(stat.)$^{+3.3}_{-2.4}$(syst.)	$11.1^{+2.3}_{-1.9}$(stat.)$^{+2.5}_{-1.9}$(syst.)	$9.4^{+2.0}_{-1.7}$(stat.)$^{+2.0}_{-1.4}$(syst.)

Cross Check (III): Electrons and Muons samples

- We measured the cross section separately for each lepton type

	Total	Electrons	Muons
$P_J < 1\%$	$8.9^{+1.0}_{-1.0}$(stat.)$^{+1.1}_{-1.0}$(syst.)	$8.6^{+1.4}_{-1.2}$(stat.)$^{+1.1}_{-1.0}$(syst.)	$9.4^{+1.7}_{-1.4}$(stat.)$^{+1.2}_{-1.0}$(syst.)
$P_J < 5\%$	$9.6^{+1.0}_{-0.9}$(stat.)$^{+1.2}_{-1.1}$(syst.)	$9.4^{+1.3}_{-1.2}$(stat.)$^{+1.2}_{-1.1}$(syst.)	$9.9^{+1.6}_{-1.4}$(stat.)$^{+1.2}_{-1.1}$(syst.)

Consistency with other results
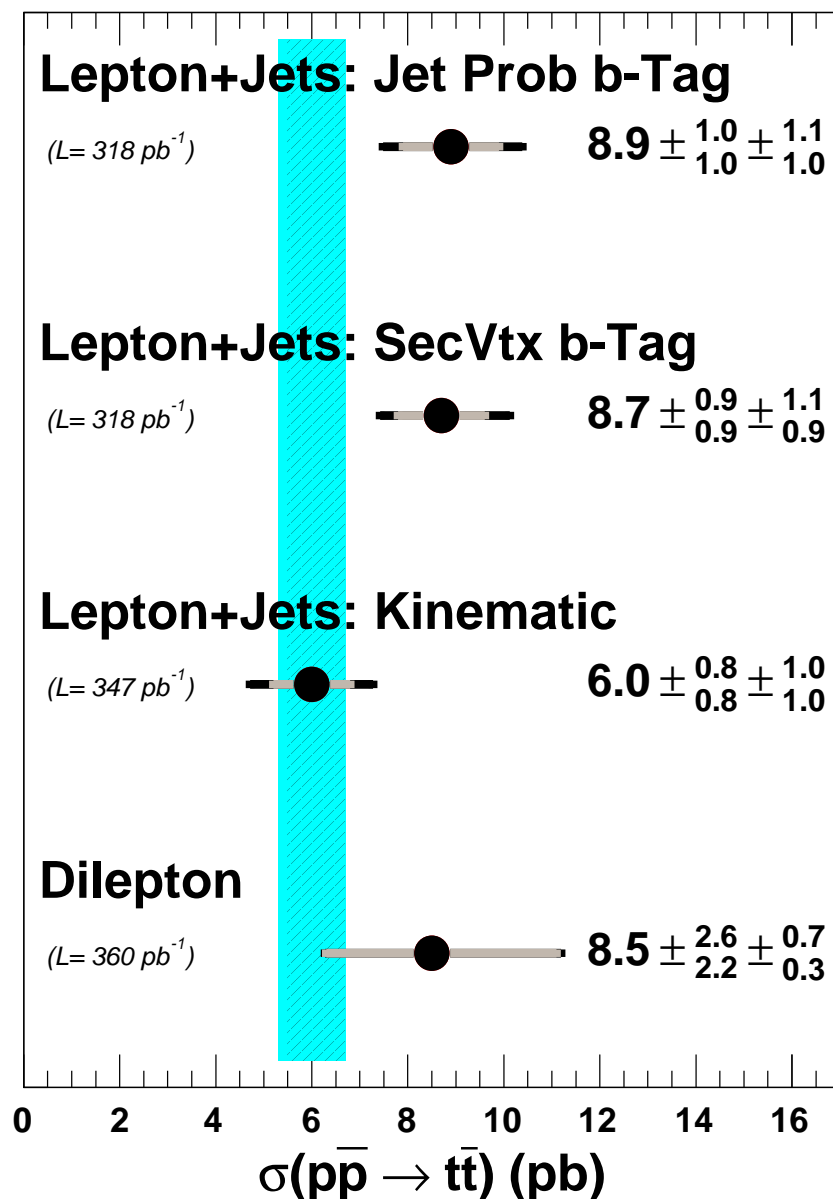
Summary

- We have developed the Jet Probability tagging algorithm for Run II

    ◇ New parameterization of S_{d_0} including silicon information

    ◇ Continuous variable based on the track impact parameter information

- Measured the efficiency using an electron data sample rich in HF

    ◇ Used a double tag method to enhance the HF content

    ◇ $54.5 \pm 3.6\%$ efficiency for $t\bar{t}$ events

- Built a mistag matrix using jet inclusive data sample

    ◇ Validated using different samples

    ◇ $1.22 \pm 0.08\%$ mistag rate

- Measured the $t\bar{t}$ production cross section in the Lepton+Jets sample

    ◇ Check the consistency of the result

    ◇ Value consistent with other measurements (and also with the theory). Total uncertainty of 17%

- Documented in several CDF internal notes

- Published in Phys. Rev. D. 74, 072006 and Phys. Rev. Lett. 97, 082004

- Shown at international conferences (APS 06, Lake Louise 06, DPF 06)

BACK-UP SLIDES

Scale Factor Dependence with the Jet E_T

- Used two different samples with high energy jets (jet20 and jet50)

- Cannot calculate the SF since we do not know the content of HF

- ... but variations on HF fractions are small for a large range of $E_T \Rightarrow$ we can estimate the E_T dependence of the SF from the E_T dependence of the ratio of positive tag excess between data and MC

- We combined the slope obtained with the 3 samples

- Slope is consistent with a flat dependence $\Rightarrow$ SF is valid at any E_T

Sample	$P_J < 1\%$	$P_J < 5\%$
Inclusive Electron	-0.0082 ± 0.0037	-0.0081 ± 0.0044
Jet 20	-0.0008 ± 0.0019	-0.0028 ± 0.0024
Jet 50	0.0005 ± 0.0008	0.0005 ± 0.0009
Weighted Average	-0.00002 ± 0.00070	-0.00020 ± 0.00072

Tag Rate Matrix Definition

Bin	E_T (GeV)	Trk. Mult.	$\sum E_T^{\text{jets}}$ (GeV)	$|\eta|$	$|Z_{\text{vtx}}|$ (cm)	ϕ
1	[0,20)	2	[0,80)	[0,1.0)	[0,10)	$[\frac{-\pi}{12}, \frac{\pi}{12})$
2	[20,35)	3	[80,140)	≥ 1.0	[10,20)	$[\frac{\pi}{12}, \frac{3\pi}{12})$
3	[35,50)	4,5	[140,220)		[20,40)	$[\frac{3\pi}{12}, \frac{5\pi}{12})$
4	[50,65)	6,7	≥ 220		[40,50)	$[\frac{5\pi}{12}, \frac{7\pi}{12})$
5	[65,80)	8,9			[50,60)	$[\frac{7\pi}{12}, \frac{9\pi}{12})$
6	[80,100)	10-13			≥ 60	$[\frac{9\pi}{12}, \frac{11\pi}{12})$
7	[100,120)	≥ 14				$[\frac{11\pi}{12}, \frac{13\pi}{12})$
8	[120,150)					$[\frac{13\pi}{12}, \frac{15\pi}{12})$
9	[150,180)					$[\frac{15\pi}{12}, \frac{17\pi}{12})$
10	≥ 180					$[\frac{17\pi}{12}, \frac{19\pi}{12})$
11						$[\frac{19\pi}{12}, \frac{21\pi}{12})$
12						$[\frac{21\pi}{12}, \frac{23\pi}{12})$

Jet Probability at CDF

- Tagger has been used by other different analysis (top mass, b physics, exotics)

- Right now, measuring the efficiencies and mistag rate using 1.2 fb^{-1} of data
  - ◇ Using a new (and complementary) method for the scale factor

  - ◇ New parameterization of the mistag rate matrix

- Usefull to provide information in other tagging strategies
  - ◇ Combined tagger

  - ◇ Neural network tagger: the jet probability variable, P_J, is going to be introduced as an input variable with a high weight

Backgrounds: Mistags (II)

- We apply tthe mistag prediction to a subsample of the lepton+jets data with $\not{E}_T < 20$ GeV and find good agreement

- But if we use the pretag lepton+jets sample there is a discrepancy

- ... due to higher HF fraction in the sample with higher value of $\not{E}_T$ with respect to the inclusive jet sample

- If we correct using the HF fractions the agreement is better
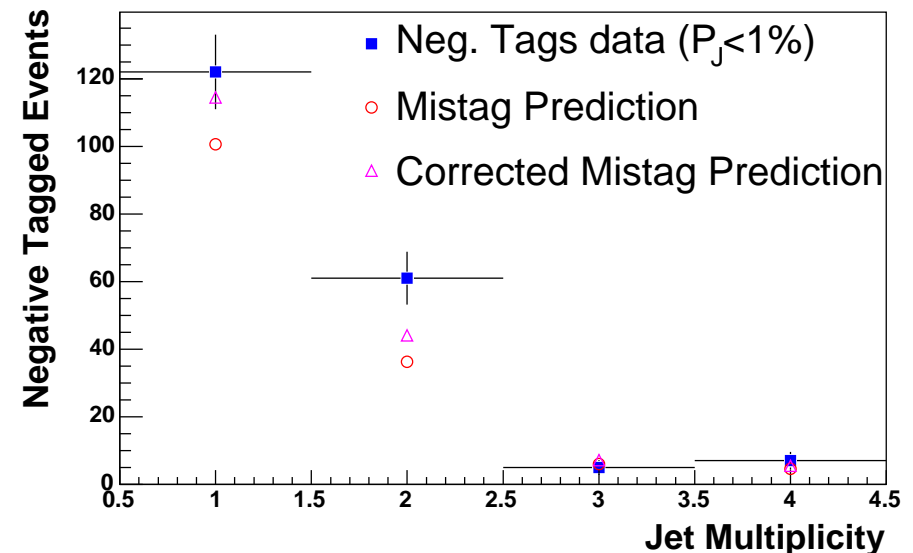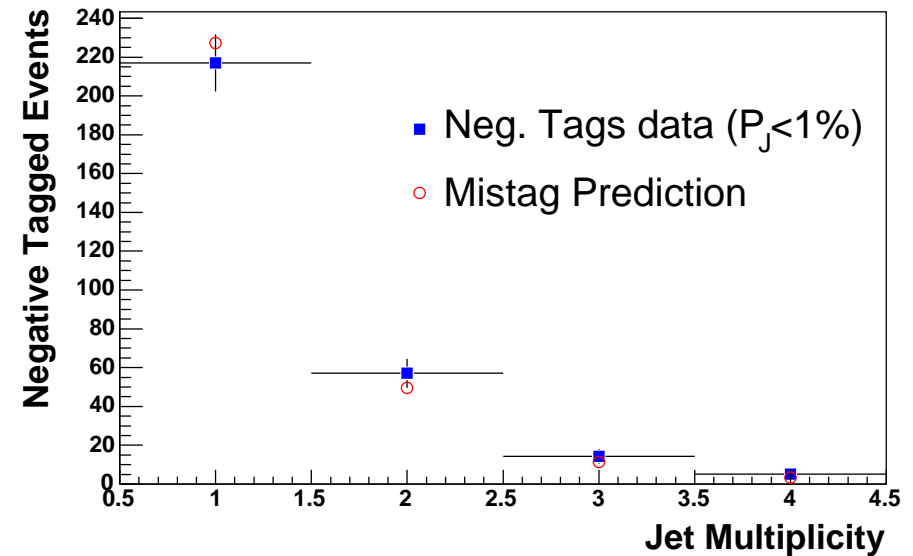
Background Summary, $P_J < 5\%$

Jet Multiplicity	1 jet	2 jets	3 jets	$\geq$ 4 jets
Pretag Data	29339	4442	300	166
Electroweak	16.3 ± 1.8	28.8 ± 3.0	4.0 ± 0.4	1.4 ± 0.1
$Wb\bar{b}$	111 ± 31	60 ± 17	5.2 ± 1.4	1.1 ± 0.3
$Wc\bar{c}$	68 ± 20	36 ± 11	3.2 ± 1.0	0.76 ± 0.24
Wc	184 ± 45	40 ± 10	2.2 ± 0.6	0.5 ± 0.13
Mistag	585 ± 92	191 ± 30	19.6 ± 3.1	6.1 ± 1.0
Non-W	69 ± 35	21 ± 11	1.3 ± 0.9	0.8 ± 0.7
Total Background	1033 ± 125	377 ± 46	35.5 ± 4.2	10.6 ± 1.4
$t\bar{t}$ (9.6 pb)	3.6 ± 0.6	28.4 ± 3.1	55.1 ± 5.7	78.6 ± 7.8
Data	975	385	87	93

Background Summary, Double tag

Jet Multiplicity	2 jets	3 jets	$\geq$ 4 jets
Pretag Data	4442	300	166
$P_J < 1\%$			
MC Derived	1.4 ± 0.3	0.33 ± 0.06	0.10 ± 0.02
$Wb\bar{b}$	6.1 ± 1.9	0.57 ± 0.19	0.10 ± 0.03
$Wc\bar{c}$	0.38 ± 0.17	0.09 ± 0.04	0.013 ± 0.008
Wc	0.12 ± 0.08	0.02 ± 0.02	0.003 ± 0.003
Mistag	0.21 ± 0.05	0.06 ± 0.01	0.019 ± 0.004
Non-W	0.19 ± 0.12	0.03 ± 0.02	0.05 ± 0.03
Total Background	8.4 ± 2.2	1.1 ± 0.3	0.28 ± 0.06
$t\bar{t}$ (11.1 pb)	3.9 ± 0.9	10.2 ± 2.0	18.4 ± 3.4
Data	13	12	18
$P_J < 5\%$			
MC Derived	2.83 ± 0.51	0.70 ± 0.12	0.25 ± 0.05
$Wb\bar{b}$	11.4 ± 3.6	1.1 ± 0.3	0.16 ± 0.05
$Wc\bar{c}$	2.3 ± 0.9	0.38 ± 0.15	0.06 ± 0.03
Wc	0.97 ± 0.37	0.16 ± 0.07	0.03 ± 0.01
Mistag	2.7 ± 0.8	0.65 ± 0.20	0.15 ± 0.05
Non-W	0.63 ± 0.34	0.09 ± 0.05	0.14 ± 0.09
Total Background	20.9 ± 5.0	3.1 ± 0.6	0.80 ± 0.15
$t\bar{t}$ (11.6 pb)	7.5 ± 1.5	20.5 ± 3.7	36.6 ± 6.1
Data	28	22	39